ANSI/NFPA 70B An American National Standard August 17, 1990

NFPA 70B
Electrical Equipment Maintenance
1990 Edition

NFPA

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Policy Adopted by NFPA Board of Directors on December 3, 1982

The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

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NFPA 70B

Recommended Practice for

Electrical Equipment Maintenance

1990 Edition

This edition of NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*, was prepared by the Technical Committee on Electrical Equipment Maintenance, and acted on by the National Fire Protection Association, Inc. at its Annual Meeting held May 21-24, 1990 in San Antonio, TX. It was issued by the Standards Council on July 20, 1990, with an effective date of August 17, 1990, and supersedes all previous editions.

The 1990 edition of this document has been approved by the American National Standards Institute.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

Origin and Development of NFPA 70B

The Board of Directors of the National Fire Protection Association in the fall of 1967 authorized the formation of an Ad Hoc Committee on Electrical Equipment Maintenance to determine the need for the development of a suitable document on this subject. The purpose of the document would be to give recommendations on the maintenance of various types of electrical installations, apparatus, and equipment usually found in industrial and large commercial-type installations. Various highly diversified interests and organizations were invited to participate.

At a meeting of the Ad Hoc Committee held January 10, 1968, in New York, with 31 representatives attending, it was pointed out that several requests had been made to the National Electrical Code Committee to include maintenance recommendations in the NEC®. The subject had been discussed by the Correlating Committee of the National Electrical Code Committee, and the decision was made that the Code was not the proper document in which to cover the maintenance of electrical equipment. However, the high frequency of electrical accidents attributed to lack of maintenance, which result annually in numerous fatalities and serious injuries as well as high monetary losses of property, caused the committee to recognize that it was a subject requiring attention.

It was noted that electrical safety information breaks down logically into four main subdivisions: (1) design or product standards; (2) installation standards (as covered by the *National Electrical Code*® and the National Electrical Safety Code); (3) maintenance recommendations; and (4) use instructions. The problem was to explore whether something more should be done in the interest of electrical safety on the maintenance of electrical equipment and what form activity in this field should take.

It was recognized that much has been done to enunciate maintenance needs for specific types of equipment by the equipment manufacturers, and that guidance is available on the general subject from a number of sources. However, it was also felt desirable to bring together some of the general guidelines in a single document under the NFPA procedure. The stature of the document would also be enhanced if it could in some way become associated with the *National Electrical Code*. To this end, a tentative scope was drafted for presentation to the Board of Directors of the National Fire Protection Association with a recommendation that an NFPA Committee on Electrical Equipment Maintenance be authorized.

On June 27, 1968, the NFPA Board of Directors authorized the establishment of an NFPA Committee on Electrical Equipment Maintenance with the following scope: "To develop suitable texts relating to preventive maintenance of electrical systems and equipment used in industrial-type applications with the view of reducing loss of life and property. The purpose is to correlate generally applicable procedures for preventive maintenance that have broad application to the more common classes of industrial electrical systems and equipment without duplicating or superseding instructions that manufacturers normally provide. Reports to the Association through Correlating Committee of the National Electrical Code Committee."

The committee was formed and an organizational meeting was held December 12, 1968, in Boston. Twenty-nine members or representatives attended. This Recommended Practice on Electrical Equipment Maintenance represents the cumulative effort of the entire committee.

In 1973, the committee developed Part II, which is Chapters 5 through 15, and a new addition in the Appendix, "How to Instruct."

In 1976, the committee developed Chapter 10, Electronic Equipment; Chapter 12, Ground-Fault Protection; Chapter 16, Wiring Devices; Chapter 19, Maintenance of Electrical Equipment Subject to Long Intervals Between Shutdowns; and new additions in the Appendix, "NEMA Configurations" and "Long-Term Maintenance Guidelines."

In the 1983 edition, the committee developed Chapter 20, De-energizing and Grounding of Equipment to Provide Protection for Electrical Maintenance Personnel; Chapter 21, Cable Tray System; and Appendix I, Equipment Storage and Maintenance During Construction, was added.

In the 1987 edition, the committee reorganized and reformatted Chapter 7 to include distribution transformers as well as power transformers.

In the 1990 edition, the committee developed Chapter 22, Maintenance of UPS Systems. This all new chapter was developed with a significant contribution from several nonmembers who joined our Ad Hoc Technical Subcommittee to produce this new material. The committee recognizes and extends its appreciation to Mr. Robert Adams, Liehert Corporation; Mr. Russ Grose, Liehert Corporation; and Mr. Ronald Mundt, U.S. Corps of Engineers. Chapter 18 was amended by the addition of diagrams of different waveshapes for detecting problems in motors and generators using surge testing.

Technical Committee on Electrical Equipment Maintenance

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This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time, changes in the membership may have occurred.

NOTE: Membership on a Committee shall not in and of itself constitute an endorsement of the Association or any document developed by the Committee on which the member serves.

Contents

NFPA 70B

Recommended Practice for

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Information on referenced publications can be found in Appendix B.

Chapter 1 General

1-1 Purpose. The purpose of this recommended practice is to reduce hazards to life and property that can result from failure or malfunction of industrial-type electrical systems and equipment. The first three chapters of these recommendations for an effective Electrical Preventive Maintenance (EPM) program have been prepared with the intent of providing a better understanding of benefits, both direct and intangible, that can be derived from a well-administered EPM program. This practice explains the function, requirements, and economic considerations that can be used to establish such a program.

1-2 Scope. This recommended practice is confined to preventive maintenance for industrial-type electrical systems and equipment, and is not intended to duplicate or supersede instructions that electrical manufacturers normally provide. Systems and equipment covered are typical of those installed in industrial plants, institutional and commercial buildings, and large multifamily residential complexes. Consumer appliances and equipment intended primarily for use in the home are not included.

1-3 Definitions.

1-3.1 Electrical Preventive Maintenance (EPM) is the practice of conducting routine inspections, tests, and the servicing of electrical equipment so that impending troubles can be detected and reduced, or eliminated.

1-3.2 *Electrical equipment* is a general term applied to material, fittings, devices, fixtures, and apparatus that are part of, or are used in connection with, an electrical installation. This includes the electrical power-generating system, substations, distribution systems, utilization equipment, and associated control, protective, and monitoring devices.

Chapter 2 Why An EPM Program Pays Dividends

2-1 Why EPM?

2-1.1 Electrical equipment deterioration is normal, but equipment failure is not inevitable. As soon as new equipment is installed, a process of normal deterioration begins. Unchecked, the deterioration process can cause malfunction or an electrical failure. Deterioration can be accelerated by factors such as a hostile environment, overload, or severe duty cycle. An effective EPM program identifies and recognizes these factors and provides measures for coping with them.

2-1.2 In addition to normal deterioration, there are other potential causes of equipment failure that may be detected and corrected through EPM. Among these are load changes or additions, circuit alterations, improperly set or improperly selected protective devices, and changing voltage conditions.

2-1.3 Without an EPM program, management assumes a much greater risk of a serious electrical failure and its consequences.

2-2 Value and Benefits of a Properly Administered EPM Program.

2-2.1 A well-administered program will reduce accidents, save lives, and minimize costly breakdowns and unplanned shutdowns of production equipment. Impending troubles can be identified — and solutions applied — before they become major problems requiring more expensive, time-consuming solutions.

2-2.2* Benefits of an effective EPM program fall in two general categories. Direct, measurable, economic benefits are derived by reduced cost of repairs and reduced equipment downtime. Less measurable but very real benefits result from improved safety. To understand fully how personnel and equipment safety are served by an EPM program, the mechanics of the program — inspection, testing and repair procedures — should be understood. Such an understanding explains other intangible benefits such as improved employee morale, better workmanship and increased productivity, less absenteeism, reduced interruption of production, and improved insurance considerations. Improved morale will come with employee awareness of a conscious management effort to promote safety by reducing likelihood of electrical injuries or fatalities, electrical explosions, and fires. Reduced personal injuries and property loss claims can help keep insurance premiums at favorable rates.

2-2.3 While benefits resulting from improved safety are difficult to measure, direct, measurable, economic benefits can be documented by equipment repair cost and equipment downtime records after an EPM program has been placed in operation.

2-2.4 Dependability can be engineered and built into equipment, but effective maintenance is required to keep it that way. Experience shows that equipment lasts longer and performs better when covered by an EPM program. In many cases, the investment in EPM is small compared to the cost of equipment repair and production losses associated with an unexpected equipment shutdown.

2-2.5 Careful planning is the key to economic success of an EPM program. With proper planning, maintenance costs will be held to a practical minimum, while production is maintained at a practical maximum.

2-2.6 Electrical preventive maintenance requires the support of top management, because it is top management who must provide funds to initiate and maintain the program. Maintenance of industrial electrical equipment is essentially a matter of business economics. Maintenance costs can be placed in either of two basic categories: (1) preventive maintenance; or (2) breakdown repairs. Money spent for preventive maintenance will be reflected as less money required for breakdown repairs. An effective EPM program holds the sum of these two expenditures to a minimum. Figure 2-4.1 is a typical curve illustrating this principle.

2-2.7 Electrical preventive maintenance is a form of protection against accidents, lost production, and loss of profit. EPM enables management to place a dollar value on the cost of such protection. An effective EPM program satisfies an important part of management's responsibility for keeping costs down and production up.

2-2.8 Insurance statistics document the high cost of inadequate electrical maintenance (*see Table A-2-2.2*). This table represents results of a study performed by only one of the major insurance groups (Factory Mutual) which specializes in industrial fire and machinery insurance. The table indicates that in a two-year period, one-half of the losses associated with electrical equipment failures might have been prevented by an effective EPM program.

2-3 EPM and Energy Conservation. A worthwhile fringe benefit of a good electrical equipment maintenance program is energy conservation — and saving dollars as well as a vital resource. Equipment that is well maintained operates more efficiently and utilizes less energy.

2-4 Case Histories: They Gambled and Lost.

2-4.1 A total plant shutdown resulted from the failure of a transformer in an industrial plant. Cause of the failure was contamination of the transformer insulating oil. The contamination went undetected because the oil had not been tested for several years. Fire damage and equipment replacement costs amounted to $50,000, exclusive of the cost of plant downtime. This amount would have paid for the cost of operating an EPM program covering the entire plant electrical distribution system for several years.

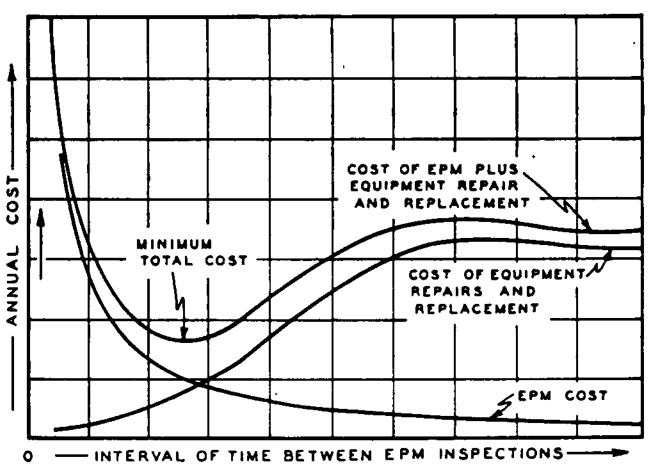

Figure 2-4.1 Effect of EPM Inspection Frequency on Overall Costs

NOTE: As the interval of time between EPM inspections is increased, cost of EPM will diminish and cost of breakdown repairs and replacement of failed equipment will increase. The lowest total annual expense is realized by maintaining an inspection frequency that will keep the sum of repair/replacement and EPM costs at a minimum.

2-4.2 Damage amounting to $100,000 was attributed to the failure of the main switchgear in an industrial plant. The failure was caused from fouling by dirt, gummy deposits, and iron filings. The cost of this failure would have supported a comprehensive EPM program covering all of the plant's electrical distribution system for several years.

2-4.3 McCormick Place, a large exhibition hall in Chicago, was destroyed by a fire believed to have been started because of a defective extension cord serving a display booth. Direct property loss was $60 million, and loss of the facility cost an additional $100 million to the economy in the Chicago area. This fire might have been prevented if a program had been in effect to ensure: that worn cords were replaced; that only heavy-duty cords were used; and that cords and their supply circuits were not overloaded.

2-4.4 Failure of a large motor shut down an entire industrial plant for 12 days. Cause of the failure was overheating resulting from dust-plugged cooling ducts. An EPM inspection would have detected the clogged ducts and averted the failure and accompanying plant outage.

Chapter 3 What Is an Effective EPM Program?

3-1 General. An effective electrical preventive maintenance program is one that enhances safety and also reduces equipment failure to a minimum consistent with good economic judgment. Basic ingredients of such a program are personnel qualified to carry out the program, and regularly scheduled inspection, testing, and servicing of equipment. Equally important to the success of the program are (1) the application of sound judgment in evaluating and interpreting results of inspections and tests, and (2) the keeping of concise, but complete, records.

3-2 Planning an EPM Program. The following basic factors should be considered when planning an EPM program:

(a) *Personnel Safety.* Will an equipment failure endanger or threaten the safety of any personnel? What can be done to ensure personnel safety?

(b) *Equipment Loss.* Is installed equipment — both electrical and mechanical — complex or so unique that required repairs would be unusually expensive?

(c) *Production Economics.* Will breakdown repairs or replacement of failed equipment require extensive downtime? How many production dollars will be lost in the event of an equipment failure? Which equipment is most vital to production?

3-3 Main Parts of an EPM Program.

3-3.1 Essential ingredients of an EPM program are:

(a) Responsible and qualified personnel.

(b) Survey and analysis of electrical equipment and systems to determine maintenance requirements and priorities.

(c) Programmed routine inspections and suitable tests.

(d) Accurate analysis of inspection and test reports so that proper corrective measures can be prescribed.

(e) Performance of necessary work.

(f) Complete but concise records.

3-3.2 A well-qualified individual should be in charge of the program. Personnel assigned to inspection and testing duties should be selected from the best maintenance personnel in the plant. Where in-plant personnel are not qualified, a maintenance contractor should be engaged.

3-3.3 Survey and analysis should cover equipment and systems that have been previously determined to be essential in accordance with a priority plan. Regardless of the size of the program being contemplated, the EPM supervisor must determine the extent of the work to be done and where to begin. Therefore, all electrical equipment — motors, transformers, circuit breakers, controls, and the like — should receive a thorough inspection and evaluation. Evaluating equipment condition and the operating environment will permit the EPM supervisor to make a qualified judgment as to how, where, and when each piece of equipment should be fitted into the program.

3-3.4 In addition to determining physical condition, the survey should determine if the equipment is operating within its rating. In the course of the survey, it is imperative that the condition of electrical protective devices be checked. Such devices include fuses, circuit breakers, protective relays, and motor overload relays. These devices are the safety valves of an electrical system. They should be in proper operating condition to ensure safety of personnel, protection of equipment, and reduction of economic loss.

3-3.5 After the survey has been completed, data should be evaluated to determine equipment condition. Equipment condition will reveal repair work to be done, as well as the nature and frequency of required inspections and tests.

3-3.6 Inspection and testing procedures should be carefully tailored to requirements. In some plants, regularly scheduled tests will call for scheduled outages of production or process equipment. In such cases, close coordination is required between maintenance and production personnel.

3-3.7 Analysis of inspection and test reports should be followed by implementation of appropriate corrective measures. Follow-through with necessary repairs, replacement, and adjustment is in fact the end purpose of an effective EPM program.

3-3.8 Records should be accurate and contain all vital information. Care should be taken to ensure that extraneous information does not become part of the record because excessive recordkeeping may hamper the program.

3-4 EPM Support Procedures.

3-4.1 Design for Ease of Maintenance. Effective electrical preventive maintenance begins with good design. In design of new facilities, conscious effort is required to ensure optimum maintainability. Dual circuits, tie circuits, auxiliary power sources, and drawout protective devices make it easier to schedule maintenance and to perform maintenance work with minimum interruption of production. Other effective design techniques include equipment rooms to provide environmental protection, grouping of equipment for more convenience and accessibility, and standardization of equipment and components.

3-4.2 Training for Technical Skills and Safety. Training programs will help ensure continuing availability of qualified manpower. Instruction, both in and out of the plant, will provide a solid foundation in technical fundamentals and safe work procedures that are necessary to work on today's sophisticated equipment.

3-4.3 Outside Service Agencies. Some maintenance and testing operations, such as relay and circuit breaker inspection and testing, require specialized skills and special equipment. In small organizations, it may be impractical to develop the skills and acquire the equipment needed for this type of work. In such cases, it might be advisable to contract the work to firms that specialize in providing such services.

3-4.4 Tools and Instruments. Proper tools and instruments are an important part of an EPM program, and safety protective gear is an essential part of the necessary equipment. Proper tools, instruments, and other equipment will ensure maximum safety and productivity from the maintenance crew. Where specialized instruments and test equipment are needed only occasionally, they can be rented from a variety of sources.

Chapter 4 Planning and Developing an Electrical Preventive Maintenance Program

4-1 Introduction.

4-1.1 The purpose of an EPM program is to reduce hazard to life and property that can result from failure or malfunction of industrial-type electrical systems and equipment. The first part of these recommendations for an effective electrical preventive maintenance (EPM) program has been prepared with the intent of providing a better understanding of benefits — both direct and intangible — that can be derived from a well-administered EPM program. This chapter explains the function, requirements, and economic considerations that can be used to establish such a program.

4-1.2 There are four basic steps to be taken in the planning and development of an electrical preventive maintenance program. In their simplest form, they are:

(a) Compile a listing of all plant equipment and systems.

(b) Determine what equipment and systems are most critical and most important.

(c) Develop a system for keeping up with what needs to be done.

(d) Train people for the work that needs to be done, or contract for the special services that are needed.

4-1.3 Success of an EPM program is dependent on the caliber of personnel responsible for its implementation. Primary responsibility for program implementation and its success should lie with a single individual. This individual should be given the authority to do the job and should have the cooperation of management, production, and other departments whose operations might affect the EPM program. Ideally, the person designated to head the EPM program should have the following qualifications:

(a) *Technical Competence.* Personnel should, by education, training, and experience, be well-rounded in all aspects of electrical maintenance.

(b) *Administrative and Supervisory Skills.* Personnel should be skilled in planning, development of long-range objectives to achieve specific results, and should be able to command respect and solicit the cooperation of all persons involved in the program.

4-1.4 The maintenance supervisor should have open lines of communication with design supervision. Frequently an unsafe installation or one requiring excessive maintenance can be traced to improper design or construction methods or misapplication of hardware.

4-1.5 The work center of each maintenance work group, whether it be a zone or total plant, should be conveniently located. This work center should contain all of the inspection and testing procedures for that zone, copies of previous reports, single-line diagrams, schematic diagrams, records of complete nameplate data, vendors' catalogs, plant stores catalogs, and supplies of report forms. There should be adequate storage facilities for tools and test equipment that are common to the group.

4-1.6 In a continuously operating plant, running inspections (inspections made with equipment operating) play a very vital role in the continuity of service. The development of running inspection procedures varies with the type of operation. However, they should be as thorough as practicable within the limits of safety and the skill of the craftsman. These procedures should be reviewed regularly in order to keep them current. Each failure of electrical equipment, be it an electrical or a mechanical failure, should be reviewed against the running inspection procedure to determine if some other inspection technique would have indicated the impending failure. If so, the procedure should be modified to reflect the findings.

4-1.7 Handling the results of running inspections is the area that gives supervisors their best motivational opportunities. When the electrical maintenance supervisor initiates corrective action, the craftsman should be so informed; the craftsman who found the condition will then feel that his job was worthwhile and will be motivated to try even harder. However, if nothing is done, individual motivation may be adversely affected.

4-1.8 Trends in failure rates are hard to change and take a long time to reverse. For this reason, the inspection should continue and resulting work orders written, even though the work force may have been reduced. Using the backlog of work orders as an indicator, the electrical maintenance supervisor can predict trends before they develop. With the accumulation of a sizable backlog of work orders, an increase in electrical failures and production downtime may be expected.

4-2 Survey of Electrical Installation.

4-2.1 Definition. The survey may be defined as the collection of accurate data on the plant electrical system and the evaluation of this data to obtain the necessary information for developing the EPM program. The systems and equipment covered in specific parts of the survey should be based on logical divisions of the overall plant, either on an electrical system or plant process basis. In some cases a combination of the two is the most suitable.

4-2.2 Data Collection.

4-2.2.1 The first step in organizing a survey is to take a look at the total "package." Will the available manpower permit the survey of an entire system, process or building, or must it be divided into segments?

4-2.2.2 Next, a priority should be assigned to each segment. Some segments may be found to be sequential, so they should be identified before the actual work commences.

4-2.2.3 The third step is the assembling of all documentation. This may necessitate a search of desks, cabinets, etc., in the plant area and may also require that manufacturers be contacted in order to replace lost documents. All of these documents should be brought to a central location and marked immediately with some form of effective identification.

4-2.3 Diagrams and Data.

4-2.3.1 The availability of up-to-date, accurate, and complete diagrams is the foundation of a successful EPM program. No EPM program can operate without them, and their importance cannot be overemphasized. The following diagrams are some of those in common use.

4-2.3.2 Single-line diagrams show the electrical circuitry down to, and often including, the major items of utilization equipment. They should show all electrical equipment in the power system and give all pertinent ratings. In making this type of diagram, it is basic that voltage, frequency, phase, and normal operating position should be included. No less important, but perhaps less obvious, are items such as transformer impedance, available short-circuit current, and equipment continuous and interrupting ratings. Other items include current and potential transformers and their ratios, surge capacitors, and protective relays. Where one diagram cannot cover all of the equipment involved, additional diagrams, appropriately noted on the main diagram, may be drawn.

4-2.3.3 Short-circuit and coordination study is very important. Many have the misconception that this engineering study is part of the initial plant design, after which the subject can be forgotten. However, a number of factors can affect the available short-circuit current in an electrical system. Among these are changes in the supply capacity of the utility company, changes in size or percent impedance of transformers, changes in conductor size, addition of motors, and system operating conditions.

(a) In the course of periodic maintenance testing of protective equipment such as relays and series or shunt-trip devices, their settings should be evaluated. Along with the proper sizing of fuses, this is part of the coordination study.

(b) In a small plant — one receiving electrical energy at utilization voltage, or from a single step-down transformer — the short-circuit study is very simple. The available incoming short-circuit current can be obtained from the utility company sales engineer.

(c) In a larger system, it may be desirable to develop a computerized short-circuit study to improve accuracy and reduce engineering time. Should facilities not be available within the plant organization, the short-circuit study can be performed on a contract basis. The short-circuit data are used to determine the required momentary and interrupting ratings of circuit breakers, fuses, and other equipment.

(d) Fuses are rated on the basis of their current-carrying and interrupting capacities. These ratings should be determined and recorded. Other protective devices are usually adjustable as to pickup point and time-current characteristics. Settings of such protective devices should be determined, verified by electrical tests, and recorded for future reference.

(e) Personnel performing the tests should be trained in proper test procedures. Several manufacturers of switchgear or test equipment have set up regularly scheduled seminars where participants are taught the principles of maintenance and testing of electrical protective devices.

4-2.3.4 Circuit routing diagrams, cable maps, or raceway layouts show the physical location of conductor runs. In addition to voltage, such diagrams should also indicate the type of raceway, number and size of conductors, and type of insulation. Where control conductors or conductors of different systems are contained within the same raceway, the coding appropriate to each conductor should be noted. Vertical and horizontal runs with the location of taps, headers, and pull boxes should be shown. Access points should be noted where raceways pass through tunnels or shafts with limited access.

4-2.3.5 Layout diagrams, plot plans, equipment location plans, or plant maps show the physical layout (and in some cases, the elevations) of the plant with all equipment in place. Switching equipment, transformers, control panels, mains, and feeders should be identified. Voltage and current ratings should be shown for each piece of equipment.

4-2.3.6 Schematic diagrams are arranged for simplicity and ease of understanding circuits without regard for the actual physical location of any components. The schematic is always drawn with switches and contacts shown in a de-energized position.

4-2.3.7 Wiring diagrams, like schematics, should show all components in the circuit, but they are arranged in their actual physical location. Electromechanical components and strictly mechanical components interacting with electrical components are shown. Of particular value is the designation of terminals and terminal strips with their appropriate numbers, letters, or colors.

4-2.3.8 Diagrams should identify all equipment parts and devices by standard methods, symbols, and markings.

4-2.3.9 Manufacturers' service manuals and instructions are required for an effective EPM program. These manuals should include recommended practices and procedures for:

(a) Installation

(b) Disassembly/Assembly (interconnections)

(c) Wiring diagrams, schematics, bills of materials

(d) Operation (set-up and adjustment)

(e) Maintenance (Including parts list and recommended spares)

(f) Software Program (if applicable)

(g) Troubleshooting

4-2.3.10 Electrical Equipment Installation Change. The documentation of the changes resulting from engineering decisions, planned revisions, etc., is the responsibility of the plant engineering group initiating the revisions.

Periodically, changes occur as a result of an EPM program. The EPM program may also uncover "undocumented practices" or installations.

A responsibility of the EPM program is to highlight these changes, note them in an appropriate manner, and formally submit the revisions to the organization responsible for the maintenance of the documentation.

4-2.4 System Diagrams.

4-2.4.1 System diagrams generally are needed to complete the data being assembled. The importance of the system determines the extent of information shown, or for a small plant, whether it is even needed. The information may be shown on the most appropriate type of diagram but should include the same basic information, source and type of power, conductor and raceway information, and switching and protective devices with their physical locations. It is vital to show where the system may interface with another, such as with emergency power; hydraulic, pneumatic, or mechanical systems; security and fire alarm systems; and monitoring and control systems. Some of the more common of these are described in 4-2.4.2 through 4-2.4.5.

4-2.4.2 Lighting system diagrams (normal and emergency) may terminate at the branch-circuit panelboard, listing the number of fixtures, type and lamp size for each area, and the design lighting level. It should show watchman lights and probably an automatic transfer switch to the emergency power system.

4-2.4.3 Ventilation systems normally comprise the heating, cooling, and air-filtering system. Exceptions include furnace, dryer, oven, casting, and similar areas where process heat is excessive and air conditioning is not practical.

Numerous fans are used to exhaust the heated and possibly foul air. In some industries, such as chemical plants and those using large amounts of flammable solvents, large volumes of air are needed to remove the hazardous vapors. Basic information, including motor and fan sizes, motor or pneumatically operated dampers, etc., should be shown. Additionally, many safety features may be involved to ensure starting of fans before the process — airflow switches to shut down an operation on loss of ventilation — and other interlocks of similar nature. Each of these should be identified with respect to type, function, physical location, and its operating limits.

4-2.4.4 Heating and air conditioning systems are usually manufactured and installed as a unit — furnished with diagrams and operating and maintenance manuals. This information should be updated as the system may be changed or modified. Because these systems are often critical to plant operation, additional equipment may have been incorporated — humidity, lint, and dust control for textile, electronic, and similar processes; corrosive and flammable vapor control for chemical and related industries, etc. Invariably these interface with other electrical or nonelectrical systems: pneumatic, or electro-mechanical operation of dampers, valves, etc.; electric operation for normal and abnormal temperature control; and manual control stations for emergency smoke removal, are just a few. There may be others, but all should be shown and complete information given for each.

4-2.4.5 Control and monitoring system diagrams are necessary to understand how these complicated systems function. They usually are in the form of a schematic diagram and may refer to specific wiring diagrams. Maximum benefit can only be obtained when every switching device is shown, its function indicated and identified for ease in finding a replacement. These often involve interfaces with other systems, whether electromechanical (heating or cooling medium) pumps and valves; electro-pneumatic temperature and damper control; or safety and emergency operations. A sequence-of-operation chart and a list of safety precautions should be included to promote safety of personnel and equipment. Understanding these complex circuits is best accomplished by breaking down the circuits into their natural functions, such as heating, cooling, process, or humidity controls. The knowledge of how each function relates to another enables the craftsman to have a better concept of the entire system and thus perform the assignment more efficiently.

4-2.5 Emergency Procedures. Emergency procedures should list, step by step, the action to be taken in case of emergency, or for the safe shutdown or start-up of equipment or systems. Optimum use of these procedures is made when they are bound for quick reference and posted in the area of the equipment or systems. Some possible items to consider for inclusion in the emergency procedures are interlock types and locations, interconnections with other systems, and tagging procedures of the equipment or systems. Accurate single-line diagrams posted in strategic places are particularly helpful in emergency situations. The production of such diagrams in anticipation of an emergency is essential to a complete EPM program. Diagrams are a particularly important training tool in developing a state of preparedness. Complete and up-to-date diagrams provide quick review of the emergency plan. During an actual emergency they provide a simple, quick-reference guide when time is at a premium.

4-2.6 Test and Maintenance Equipment.

4-2.6.1 All maintenance work requires the use of proper tools and equipment to properly perform the task to be done. In addition to their ordinary tools, each craftsman (such as carpenters, pipe fitters, and machinists) uses some special tools or equipment based on the nature of the work to be performed. The electrician is no exception, but for EPM, additional equipment not found in the toolbox should be readily available. The size of the plant; nature of its operations; extent of its maintenance, repair, and test facilities; are all factors that determine the use-frequency of the equipment. Economics seldom justify purchasing an infrequently used, expensive tool when it can be rented. However, a corporation having a number of plants in the area may well justify common ownership of the same device for joint use, making it quickly available at any time to any plant. Typical examples might be high-current or dc high-potential test equipment, or a ground-fault locator.

4-2.6.2 A certain amount of mechanical maintenance is often a part of the EPM program being conducted on associated equipment. The electrical craftsman should have ready access to such items as assorted lubrication tools and equipment; various types and sizes of wrenches; nonmetallic hammers and blocks to protect against injury to machined surfaces; wheel pullers; feeler gages; inside- and outside-diameter measuring gages; instruments for measuring torque, tension, compression, vibration, and speed; standard and special mirrors with light sources for visual inspection; portable blowers and vacuums of industrial type having insulated nozzles for removal of dust and foreign matter; nontoxic, nonflammable cleaning solvents; and clean, lint-free wiping cloths.

4-2.6.3 The use of well-maintained safety equipment is essential and should be mandatory when working on or near live electrical equipment. Some of the more important articles needed are heavy leather gloves; insulating gloves, mats, blankets, baskets, boots, jackets and coats; insulated hand tools such as screwdrivers and pliers; nonmetallic hard hats with clear insulating face shields for protection against arcs; poles with hooks and hot sticks to safely open isolating switches. A statiscope is desirable to indicate the presence of high voltage on certain types of equipment.

4-2.6.4 Portable electric lighting is often necessary, particularly in emergencies involving the plant power supply. Portable electric lighting used for maintenance areas that are normally wet or where personnel will be working within grounded metal structures such as drums, tanks, and vessels should be operated at an appropriate low voltage from an isolating transformer or other isolated source. This voltage level is a function of the ambient condition in which the portable lighting is used. The aim is to limit the exposure of personnel to hazardous current levels by limiting the voltage. Ample supply of battery lanterns should be available with extra batteries. Suitable extension cords are usually necessary.

4-2.6.5 Portable meters and instruments are necessary for testing and troubleshooting, especially on circuits of 600 volts or less. These include general-purpose volt meters, volt-ohmmeters, and clip-on-type ammeters with multi-scale ranges. In addition to these conventional instruments, recording meters are useful for measuring magnitudes and fluctuations of current, voltage, power factor, watts, and volt-amperes versus time values. These are a definite aid in defining specific electrical problems and determing if equipment malfunction is due to abnormal electrical conditions. Other valuable test equipment includes devices to measure insulation resistance of motors and similar equipment in the megohm range and similar instruments in the low range for determining ground resistance, lightning protection systems, and grounding systems. Continuity testers are particularly valuable for checking control circuits and for circuit identification.

4-2.6.6 Special instruments can be used to test the impedance of the grounding circuit, or conductor, or path on energized low-voltage distribution systems. These instruments may be be used to test the equipment grounding circuit of electric equipment.

4-2.6.7 Insulation-resistance-measuring equipment should be used to indicate insulation values at the time equipment is put into service. Later measurements may indicate any deterioration trend of the insulation values of the equipment. High-potential ac and dc testers are used effectively to indicate dielectric strength and insulation resistance of the insulation respectively. It should be recognized that the possibility of breakdown under test due to concealed weakness is always present. High-potential testing should be performed with caution and only by qualified operators.

4-2.6.8 Portable ground-fault locators can be used to test ungrounded power systems. Such devices will indicate ground location while the power system is energized. They are thus a valuable aid for safe operation by indicating where to take corrective steps before an insulation breakdown occurs on another phase.

4-2.6.9 Receptacle circuit testers are devices that, by a pattern of lights, indicate some types of incorrect wiring of 15- and 20-ampere, 125-volt grounding-type receptacles.

Although these test devices can provide useful and easily acquired information, some have limitations and the test results must be used with caution. For example, a high-resistance ground can give a correct wiring display as will some multiple wiring errors. An incorrect display can be considered a valid indication that there is an incorrect situation, but a correct wiring display should not be accepted without further investigation.

4-3 Identification of Critical Equipment.

4-3.1 Equipment (electrical or otherwise) is considered critical if its failure to operate normally and under complete control will cause a serious threat to people, property, or the product. Electric power, like process steam, water, etc., may be essential to the operation of a machine, but unless loss of one or more of these supplies causes the machine to become hazardous to people, property, or production, that machine may not be critical. The combined knowledge and experience of several people may be needed to make this determination. In a small plant this can probably be done by the plant engineer or master mechanic working with the operating superintendent. A large operation may need a "team" comprising the following qualified people: (1) the electrical foreman or superintendent; (2) production personnel thoroughly familiar with the operation capabilities of the equipment and the effect its loss will have on final production; (3) the senior maintenance person who is generally familiar with the maintenance and repair history of the equipment or process; (4) a technical person knowledgeable in the theoretical fundamentals of the process and its hazards (in a chemical plant he should be a chemist; in a mine, a geologist, etc); and (5) a safety engineer or one responsible for the overall security of the plant and its people against fire and accidents of all kinds. They should go over the entire plant or each of its operating segments in detail, considering each unit of equipment as related to the entire operation, and the effect of its loss on safety and production.

4-3.2 There are entire systems that may be critical by their very nature. Depending on the size of the plant and the complexity of the operation, it may contain any or all of the examples listed: emergency power, emergency lighting, fire alarm systems, fire pumps, and certain communication systems. There should be no problem in establishing whether or not any of these systems is critical and in having the proper amount of emphasis placed on their maintenance.

4-3.3 More difficult to identify are the parts of a system that are critical because of the function of the utilization equipment and its associated hardware. Some examples are:

(a) The agitator drive motor for a kettle-type reactor may be extremely critical in that, if it fails to run for some period of time, when the charge materials are added to the reactor, the catalyst stratifies. If the motor is then started, rather than a slow, controlled reaction, a rapid reaction could result that may run away, over-pressurize, and destroy the reactor.

(b) The cooling water source of an exothermic reactor may have associated with it some electrical equipment such as a drive motor, solenoid valves, controls, or the like. The failure of this cooling water may allow the exothermic reaction to go beyond the stable point and overpressurize and destroy the vessel.

(c) A process furnace recirculating fan drive motor or fan may fail, nullifying the effects of temperature-sensing points allowing hot spots to develop with serious side reactions.

(d) The failure of gas analysis equipment and interlocks in a drying oven or annealing furnace may allow the atmosphere in the drying oven or furnace to become flammable with the possibility of an explosion.

(e) The failure of any of the safety combustion controls on a large fire box, such as a boiler or incinerator, may cause a serious explosion.

(f) Two paralleled pump motors may be needed to provide the total requirements of a continuous process. Failure of either of these motors may cause a complete shutdown, rather than simply reduce production.

4-3.4 There are parts of the system that are critical because they reduce the widespread effect of a fault in electrical equipment. The determination of these is primarily the responsibility of the electrical person on the team. Among the things that fall in this category are:

(a) Source overcurrent protective devices, such as circuit breakers or fuses. This includes the relays and control circuits. It also includes the coordination of trip characteristics of the devices.

(b) Automatic bus transfer switches or other transfer switches that would supply critical loads with power from the emergency power source if the primary source failed. This includes instrument power supplies as well as load power supplies.

4-3.5 Parts of the control system are critical because they monitor the process and automatically shut down equipment or take other action to prevent catastrophe. These items are the interlocks, cutout devices, or shutdown devices installed throughout the plant or operation. Each of these interlocks or shutdown devices should be carefully considered by the entire team to establish whether or not they are critical shutdowns or whether they are "convenience" shutdowns. It should be thoroughly understood by the maintenance group which shutdowns are critical and which are convenience. The critical shutdown devices are normally characterized by having a sensing device separate from the normal control device. It probably has a separate, final, or end device that causes action to take place. Once the critical shutdown systems are recognized, they should be distinctly identified on drawings, on records, and on the hardware itself. Some examples of critical shutdown devices are: overspeed trips, high or low temperature, pressure, flow or level trips, low lube-oil pressure trips, pressure-relief valves, overcurrent trips, and low-voltage trips.

4-3.6 There are parts of the system that are critical because they alert operating personnel to dangerous or out-of-control conditions. These are normally referred to as alarms. Like shutdown devices, alarms fall into at least three categories: (1) those that signify a true pending catastrophe; (2) those that indicate out-of-control conditions; and (3) those that indicate the end of an operation or similar condition. The entire team should consider each alarm in the system with the same thoroughness with which they have considered the shutdown circuits. The truly critical alarm should be characterized by having a separate sensing device, a separate readout device, and preferably, separate circuitry and power source. The maintenance department should thoroughly understand the critical level of each of the alarms. The critical alarms and their significance should be distinctly marked on drawings, in records, and on the operating unit. For an alarm to be critical does not necessarily mean that it is complex or related to complex action. A simple valve position indicator may be one of the most critical alarms in an operating unit.

4-4 Establishment of a Systematic Program.

4-4.1 The purpose of any inspection and testing program is to establish the condition of equipment to determine what work should be done and to verify that it will continue to function until the next scheduled servicing occurs. Inspection and testing is best done in conjunction with routine maintenance. In this way, many minor items that require no special tools, training, or equipment can be corrected as they are found. The inspection and testing program is probably the most important function of a maintenance department in that it establishes what needs to be done to keep the system in service to perform the function for which it is required.

4-4.2 Atmosphere or Environment.

4-4.2.1 The atmosphere or environment in which electrical equipment is located has a definite effect on its operating capabilities and the degree of maintenance required. An ideal environment is one in which the air is: (1) clean or filtered to remove dust, harmful vapor, excess moisture, etc.; (2) maintained in the temperature range of 60°F (15°C) to 85°F (29°C); and (3) in the range of 40-70 percent humidity. Under such conditions the need for maintenance will be minimized. Where these conditions are not maintained, the performance of electrical equipment will be adversely affected. Good housekeeping contributes to a good environment and reduced maintenance.

4-4.2.2 Dust can foul cooling passages and thus reduce the capabilities of motors, transformers, switchgear, etc., by raising their operating temperatures above rated limits, decreasing operating efficiencies, and increasing fire hazard. Similarly, chemicals and vapors can coat and reduce the heat transfer capabilities of heating and cooling equipment. Chemicals, dusts, and vapors can be highly flammable, explosive, or conductive, increasing the hazard of fire, explosion, ground faults, and short circuits. Chemicals and corrosive vapors can cause high contact resistance that will decrease contact life and increase contact power losses with possible fire hazard or false overload conditions due to excess heat. Large temperature changes combined with high humidity can cause condensation problems, malfunction of operating and safety devices, and lubrication problems. High ambient temperatures in areas where thermally sensitive protective equipment is located can cause such protective equipment to operate below its intended operating point. Ideally, both the electrical apparatus and its protective equipment should be located within the same ambient. Where the ambient temperature difference between equipment and its protective device is extreme, compensation in the protective equipment should be made.

4-4.3 Load Conditions.

4-4.3.1 Equipment is designed and rated to perform satisfactorily when subjected to specific operating and load conditions. A motor designed for safe continuous operation at rated load may not be satisfactory for frequent intermittent operation that can produce excessive winding temperatures or mechanical trouble. The resistance grid or transformer of a reduced-voltage starter will overheat if left in the starting position. So-called "jogging" or "inching" service imposes severe demands on equipment such as motors, starters, and controls. Each type of duty influences the type of equipment used and the extent of maintenance required. The five most common types of duty are defined in the National Electrical Code, and they are repeated in 4-4.3.2 below.

4-4.3.2 Duty is defined as:

(a) *Continuous:* Operation at a substantially constant load for an indefinitely long time.

(b) *Intermittent:* Operation for alternate intervals of (1) load and no load; (2) load and rest; (3) load, no load, and rest.

(c) *Periodic:* Intermittent operation in which the load conditions are regularly recurrent.

(d) *Short-time:* Operation at a substantially constant load for a short and definitely specified time.

(e) *Varying:* Operation at loads, and for intervals of time, both of which may be subject to wide variation.

4-4.3.3 Some devices that may be of use in establishing a proper maintenance period are: running-time meters (to measure total "on" or "use" time); counters to measure number of starts, stops or load on, load off and rest periods; and recording ammeters to graphically record load and no-load conditions. These devices can be applied to any system or equipment and will help classify the duty. This will help establish a proper frequency of preventive maintenance.

4-4.3.4 Safety and limit controls are devices whose sole function is to assure that values remain within the safe design level of the system. Each device should be periodically and carefully inspected, checked, and tested to be certain that it is in reliable operating condition because it functions only during an abnormal situation where an undesirable or unsafe condition is reached.

4-4.4 Wherever practical, a history of each electrical system should be developed for all equipment or parts of a system vital to a plant's operation, production, or process. The record should include all pertinent information for proper operation and maintenance. This information is useful in developing repair cost trends, items replaced, design changes or modifications, significant trouble or failure patterns, and replacement parts or devices that should be stocked. System and equipment information should include:

(a) Types of electrical equipment — motors, starters, contactors, heaters, relays.

(b) Types of mechanical equipment — valves, controls, etc., and driven equipment such as pumps, compressors, fans — and whether they are direct, geared, or belt driven.

(c) Nameplate data.

(d) Equipment use.

(e) Installation date.

(f) Available replacement parts.

(g) Maintenance test and inspection date — type and frequency of lubrication; electrical inspections, test, and repair; mechanical inspection, test, and repair; replacement parts list with manufacturer's identification; electrical and mechanical drawings for assembly, repair, and operation.

4-4.5 Inspection Frequency.

4-4.5.1 Those pieces of equipment found to be critical should require the most frequent inspections and tests. Depending on the degree of reliability required, other items may be inspected and tested much less frequently.

4-4.5.2 Manufacturers' service manuals should have a recommended frequency of inspection. The frequency given is based on "standard" or "usual" operating conditions and environments. It would be impossible for the manufacturer to list all combinations of environmental and operating conditions. However, this is a good basis from which to begin considering the frequency for inspection and testing.

4-4.5.3 There are several points to consider in establishing the initial frequency of inspections and tests. Electrical equipment located in a separate air-conditioned control room or switch room certainly would not be considered normal, so the inspection interval might be extended 30 percent. However, if the equipment is located near another unit or operating plant that discharges dust or corrosive vapors, it might reduce this time as much as 50 percent.

4-4.5.4 Continuously operating units with steady loads or with less than the rated full load would tend to operate much longer, and more reliably, than intermittently operated or standby units. For this reason, the interval between inspections might be extended 10 to 20 percent for continuously operating equipment and possibly reduced by 20 to 40 percent for standby or infrequently operated equipment.

4-4.5.5 Once the initial frequency for inspection and tests has been established, this frequency should be adhered to for at least four maintenance cycles unless undue failures occur. For equipment that has unexpected failures, the interval between inspections should be reduced by 50 percent as soon as the trouble occurs. On the other hand, after four cycles of inspections have been completed, a pattern should have developed. If equipment consistently goes through more than two inspections without requiring service, the inspection period may be extended by 50 percent. Loss of production due to an emergency shutdown is almost always more expensive than loss of production due to a planned shutdown. Accordingly, the interval between inspections should be planned to avoid the diminishing returns of either too long or too short an interval.

4-4.5.6 This adjustment in the interval between inspections will continue until the optimum interval is reached. This adjustment time can be minimized and the optimum interval approximated more closely initially by providing the person responsible for establishing the first interval with as much pertinent history and technology as possible.

4-4.5.7 The frequency of inspection for similar equipment operating under different conditions may need to be widely different.

Typical examples illustrating this are:

(a) In a continuously operating plant having a good load factor and located in a favorable environment, the high-voltage oil circuit breakers may only need an inspection every two years. On the other hand, an electrolytic process plant using similar oil circuit breakers for controlling furnaces may find it necessary to inspect and service them as frequently as every 7 to 10 days.

(b) An emergency generator to provide power for noncritical loads may be tested on a monthly basis. Yet the same generator in another plant having processes sensitive to explosion on loss of power may need to be tested each shift.

4-5 Methods and Procedures.

4-5.1 General.

4-5.1.1 If a system is to operate without failure, not only should the discrete components of the system be maintained, but the connections between these components should also be covered by a thorough set of methods and procedures. Overlooking this important link in the system causes many companies to suffer high losses every year.

4-5.1.2 Other areas where the maintenance department should develop their own procedures are shutdown safeguards, interlocks, and alarms. Although the individual pieces of equipment may have testing and calibrating procedures furnished by the manufacturer, the application is probably unique, so that the system, per se, should have an inspection and testing procedure developed for it.

4-5.2 Forms.

4-5.2.1 A variety of forms may go along with the Inspection, Testing, and Repair (IT&R) procedure. They should be detailed and direct, yet simple and durable enough to be used in the field. Field notes taken should be legibly transcribed. One copy of reports should go in the working file of the piece of equipment and one in the master file maintained by first line supervision. These forms should be used by the electrical maintenance people. They are not for general distribution. If reports to production or engineering are needed, they should be separate, and inspection reports should not be used.

4-5.2.2 The IT&R procedure folder for a piece of equipment should have listed in it:

(a) All the special tools, materials, and equipment necessary to do the job.

(b) The estimated or actual average time to do the job.

(c) Appropriate references to technical manuals.

(d) Previous work done on the equipment.

(e) Points for special attention indicated by previous IT&R. If major work was predicted at the last IT&R, the procedure folder should contain a copy of the purchase order and receiving reports for the parts to do the work. It should contain references to unusual incidents reported by production that may be associated with the equipment.

4-5.2.3 Special precautions relative to operation should be part of the IT&R document. What other equipment is affected and in what way? Who has to be informed that the IT&R is going to be done? How long will the equipment be out of service if all goes well and also if major problems are uncovered?

4-5.3 Planning.

4-5.3.1 Having developed the IT&R procedures and having the frequency established (even though preliminary), now comes the task of scheduling. Scheduling in a continuous-process plant (as opposed to a batch-process plant) is most critically affected by availability of equipment in blocks consistent with maintenance manpower capabilities. In general, plants will be shut down on some regular basis for overall maintenance and repair. Some of the electrical maintenance items should be done at this time. IT&R that could be done while equipment is in service should be done prior to shutdown. Only work that needs be done during shutdown should be scheduled at that time — to level out manpower requirements and to limit downtime.

4-5.3.2 The very exercise of scheduling IT&R will point out design weaknesses that require excessive manpower during critical shutdown periods or require excessive downtime to do the job with the personnel available. Once these weaknesses have been uncovered, consideration can be given to rectifying them. For example, the addition of one circuit breaker and a little cable may change a shutdown from three days to one day.

4-5.3.3 Availability of spare equipment affects scheduling in many ways. Older plants may have installed spares for a major part of the equipment, or the plant may be made up of many parallel lines so that they may be shut down, one at a time, without seriously curtailing production. This concept is particularly adaptable to electrical distribution. Use of a circuit breaker and a transfer bus may extend the interval between total shutdown on a main transformer station from once a year to once in 5 years or more.

4-5.3.4 In many continuous-process plants, particularly the newer ones, the trend is toward a large single-process line with no installed spares. This method of operation will require running inspections and running tests since there will be a natural desire to extend the time between maintenance shutdowns. Downtime in such plants will be particularly costly, so it is desirable to build as much monitoring into the electrical systems as possible.

4-5.3.5 Planning running inspections can vary from a simple desk calendar to a computer program. Any program for scheduling should have four facets: (1) a reminder to order parts and equipment with sufficient lead time to have them on the job when needed; (2) the date and manhours to do the job; (3) a check to see that the job has been completed; and (4) noticing if parts are needed for the next IT&R and when they should be ordered.

4-5.3.6 Planning shutdown IT&R is governed by the time between shutdowns established by the limitations of the process or production units involved. Reliability of electrical equipment can and should be built in to correspond to almost any length of time.

4-5.3.7 Small plants will want to utilize, in a much abbreviated form, the following shutdown recommendations of a large plant IT&R:

(a) Know how many personnel-shifts the work will take.

(b) Know how many persons will be available.

(c) Inform production how many shifts the electrical maintenance will require.

(d) Have all the tools, materials, and spare parts that will be required assembled on the job site. Overage is better than shortage.

(e) Plan the work so that each person is used to best suit his skills.

(f) Plan what each person will be doing each hour of the shutdown. Allow sufficient off time so that if a job is not finished as scheduled, the person working on that job can be held over without overtiring them for the next shift. This will allow the schedule to be kept.

(g) Additional clerical people during shutdown IT&R will make the job go smoother, help prevent missing some important function, and allow an easier transition back to normal.

(h) Supply copies of the electrical group plan to the overall shutdown coordinator so that it can be incorporated into the overall plan. The overall plan should be presented in a form that is easy to use by all levels of supervision. In a large complex operation, a critical path program or some similar program should be used.

4-5.3.8 Automatic shutdown systems and alarm systems that have been determined as critical should be so designed and maintained that nuisance tripping does not destroy operator confidence. Loss of operator confidence can and will cause these systems to be bypassed and the intended safety lost. Maintenance should prove that each operation was valid and caused by an unsafe condition.

4-5.3.9 A good electrical preventive maintenance program should identify the less critical jobs, so it will be clear to first-line supervision which EPM can be delayed to make personnel available for emergency breakdown repair.

4-5.4 Analysis of Safety Procedures.

4-5.4.1 It is beyond the scope of this recommended practice to cover details of safety procedures for each of the IT&R activities. Manufacturers' instructions contain safety procedures required in using their test equipment.

4-5.4.2 The test equipment (high voltage, high current, or other uses) should be inspected in accordance with vendor recommendations before the job is started. Any unsafe condition should be corrected before proceeding.

4-5.4.3 The people doing the IT&R should be briefed to be sure that all facets of safety before, during, and after the IT&R are understood. It is important that all protective equipment is in good condition and is on the job.

4-5.4.4 Screens, ropes, guards, and signs needed to protect people other than the IT&R team should be provided and used.

4-5.4.5 A procedure should be developed, understood, and used for leaving the test site in a safe condition when unattended. These times may include a smoke break, a lunch break, or even overnight.

4-5.4.6 A procedure should be developed, understood, and used to ensure safety to and from the process before, during, and after the IT&R. The process or other operation should be put in a safe condition for the IT&R by the operating people before the work is started. The procedure should include such checks as are necessary to ensure that the unit is ready for operation after the IT&R is completed and before the operation is restarted.

4-5.5 Records.

4-5.5.1 Sufficient records should be kept by maintenance management to evaluate results. Analysis of the records should guide the spending level for EPM and breakdown repair.

4-5.5.2 Figures should be kept to show the total cost of each breakdown. This should be the actual cost plus an estimated cost of the business interruption. This figure is a powerful indicator for the guidance of expenditures for EPM.

4-5.5.3 Records Kept by First Line Supervisor of EPM. Of the many approaches to this phase of the program, the following is a typical set that fulfills the minimum requirements:

(a) *Inspection Schedule.* The first line supervisor should maintain, in some easy-to-use form, a schedule of inspections so that he can plan manpower requirements.

(b) *Work Order Log.* An active log should be kept of unfinished work orders. A greater susceptibility to imminent breakdown is indicated by a large number of outstanding work orders resulting from the inspection function.

(c) *Unusual Event Log.* As the name implies, this lists unusual events that affect the electrical system in any way. This record is derived from reports of operating and other personnel. This is a good tool for finding likely problems after the supervisor has learned to interpret and evaluate the reports. This is the place where near misses can be recorded and credit given for averting trouble.

4-5.6 Emergency Procedures. It should be recognized that properly trained electrical maintenance personnel have the potential to make a very important contribution in the emergency situations that are most likely to occur. However, most such situations will also involve other crafts and disciplines, such as operating personnel, pipe-fitters, and mechanics. An overall emergency procedure for each anticipated emergency situation should be cooperatively developed by qualified personnel of each discipline involved, detailing steps to be followed, sequence of steps, and assignment of responsibility. The total procedure should then be run periodically as an emergency drill to assure that all involved personnel are kept thoroughly familiar with the part they must perform.

4-6 Maintenance of Foreign-made Electrical Equipment.

4-6.1 Equipment of foreign manufacture poses some additional maintenance problems not usually associated with American-made equipment.

4-6.2 Quick delivery of replacement parts cannot be taken for granted. Suppliers should be identified, and the replacement parts problem should be reflected in the inplant spare parts inventory. In addition to considering possible slow delivery of replacement parts, knowledgeable outside sources of foreign maintenance engineering services should be established.

4-6.3 English-written parts catalogs, maintenance manuals, and drawings should be available. In contrast with literature and drawings developed by American manufacturers, these should not be automatically presumed to be understandable. Problems in translation should be identified as soon as literature is received, to ensure that material will be fully understood later when actual maintenance must be performed.

Chapter 5 Fundamentals of Electrical Equipment Maintenance

5-1 Design to Accommodate Maintenance.

5-1.1 Except for limited visual inspection, such as observing operating temperatures, examination for contamination, recording load readings, etc., the apparatus must be taken out of service to perform efficient and effective maintenance. Unless flexibility is built into the electrical system in the way of duplication or alternate transfer schemes, maintenance of vital electrical apparatus must be scheduled with planned production outages.

5-1.2 An example of flexibility is a selective radial distribution system incorporating double-ended low-voltage substations. This permits maintenance and testing to be performed on equipment such as the primary feeders, transformers, and main and tie circuit breakers during periods of light loads.

5-1.3 Larger production equipment, such as air compressors, air-conditioning units, pumps, etc., that can be difficult to repair or replace quickly, are often installed in multiples to provide reserve capacity. Duplication of equipment enables maintenance to be performed economically without costly premium time and ensures continuous production in the event of an accidental breakdown.

5-1.4 Selection of quality equipment, adequate for the present and projected load growth, is a prime factor in reducing maintenance cost. Overloaded equipment or equipment not suited for the application will have a short service life and will be costly to maintain. Abnormal conditions, such as corrosive atmosphere, excessive temperature, high humidity, abrasive or conducting particles, and frequent starting and stopping, require special consideration in the selection of the equipment in order to minimize maintenance cost.

5-1.5 Too often, installed cost without sufficient regard for performing efficient and economic maintenance influences system design. Too often, within a few years, the added cost of performing maintenance plus production loss from forced outages due to lack of maintenance will more than offset the saving in initial cost.

5-1.6 As equipment grows older, and is possibly worked harder, scheduling outages to perform accelerated maintenance could become a major problem.

5-2 Scheduling Maintenance.

5-2.1 In the larger plants, routine maintenance scheduling is often done on a computer. The computer is programmed to print out the work orders for the projects to be accomplished on a weekly or monthly basis. To the opposite extreme, in smaller plants, the maintenance schedule is often carried in the maintenance supervisor's head. It goes without saying, an effective maintenance program requires a positive mechanism for scheduling and recording of the work accomplished.

5-2.2 A most thankless task is that of working with production management in attempting to obtain production outages necessary to accommodate maintenance. As yet, most production managers look on maintenance as a necessary evil. Maintenance outages, particularly in plants that operate 24 hours per day, seven days a week, are difficult to come by; however, there are some areas that can be relieved with a nominal investment.

For example, low-voltage power circuit breakers should be inspected on an annual basis and tested under simulated overload and fault conditions every three to five years. An investment in a few spare circuit breakers, one or two of each make and size in use, would allow them to be inspected, overhauled, and tested at almost any convenient time. The inservice breakers could then be exchanged with a spare at an opportune time, with negligible production downtime.

5-2.3 Many plants schedule vacation shutdowns of from one to three weeks duration to perform needed periodic maintenance on vital production apparatus that cannot be taken out of service at any other time. A total plant shutdown resolves the problem of scheduling partial outages around limited production operations. Even so, some difficulty may be encountered in providing power requirements for maintenance operations and still perform the needed maintenance on the electrical system.

5-2.4 Performing preventive maintenance with overtime labor, such as Saturdays, Sundays, holidays, and after regular hours is costly — an expense not kindly accepted by management. The scope of the work must be confined to the limited time and available personnel. Contracting out preventive maintentance to qualified electrical contractors can relieve these and other problems associated with preventive maintenance. Electrical contractors who specialize in this type of work have trained mechanics and the proper tools and equipment. Many of them carry inventories of spare electrical equipment.

5-3 Personnel and Equipment Safety.

5-3.1 Consideration of personnel safety, in addition to equipment safety, must be given prime consideration in system design and in establishing adequate maintenance practice. The principal personnel danger from electricity is that of shock, electrocution, and/or severe burns from the electrical arc or its effects; which may be similar to that of an explosion. It should be of interest to know that the small current drawn by a 7.5-watt, 120-volt lamp, if passed from hand to hand, or hand to foot, could be fatal.

5-3.2 Destructive energy, capable of disintegrating an entire switchgear assembly in a matter of a few minutes, can be released in a low-voltage phase-to-phase, or phase-to-enclosure, sustained arcing fault. The fault current, in the order of thousands of amperes, multiplied by the arc voltage drop (approximately 100 volts on a 480Y/277 system) multiplied by the duration of the arc in seconds is a measure of the energy released (watt-seconds).

5-3.3 Personnel safety must be an integral part of maintenance practices. As a general rule, no electrical apparatus should be worked on while it is energized. When it is necessary to work in the vicinity of energized equipment, all safety precautions should be followed, such as roping off the dangerous area, using rubber blankets for isolation, and using rubber gloves and properly insulated tools and equipment. All insulating tools such as rubber gloves and blankets should be periodically tested.

5-3.4 Switches or circuit breakers should be locked in an open position and tagged to provide information as to why the circuit is open and the name of the person having the key for the lock. ANSI Standard Z244.1-1974 is suggested as a guide in developing an effective lockout/tagout for electrical and other energy sources. Where the practice of utilizing a protective ground is followed, the grounding device should be of adequate capacity and securely attached to cause the circuit protective device to function before the grounding device burns off, should the circuit be accidentally energized.

5-3.5 Equipment safety demands sensitive and effective protection. The protective device must be capable of immediately sensing the abnormality and cause it to be isolated with the least destruction and minimum disturbance to the system. The degree of sensitivity and speed of response is most vital to the effectiveness of the protection.

5-3.6 The protective device, fuse, relay and series or static trip on low-voltage breakers generally sense overcurrent. Ideally, the device should not be applied or set to respond to normal load excursions yet it should function on a low-level fault. This is an impossible situation unless ground-fault protection is utilized, since the magnitude of a phase-to-ground fault could be less than normal load current.

5-4 The Protective Scheme.

5-4.1 While the application of circuit protection, as developed in a short circuit and coordination study, is an engineering function and hence recognized as a facet of system design, assurance that this designed protection remains in operation is a maintenance responsibility. Applying the settings and periodic testing of the protective devices, relays and series and static trip elements is definitely a maintenance function. Similarly, the checking of the proper type and ampere rating of the fuses used in the system is part of the maintenance function.

5-4.2 In the larger plants, the interpretation of the short circuit and coordination study is generally made by plant engineering, and the settings and test points for the adjustable protective devices are furnished by the maintenance department, as are the type and ampere rating of the fuses. While the maintenance personnel need not be able to make the engineering study, they should be able to interpret the time-current curves in understanding the performance of the protective device under test.

5-4.3 An up-to-date short circuit and coordination study is essential for safety of personnel and equipment. It is necessary to analyze the momentary and interrupting rating requirements of the protective devices. That is, will the circuit breaker or fuse safely interrupt the fault or explode in attempting to perform this function?

Another phase of the study is that of developing the application of the protective device to realize minimum equipment damage and the least disturbance to the system, in the event of a fault.

5-5 Acceptance Testing.

5-5.1 The initial acceptance testing of the electrical system is part of design and plant construction and hence not part of maintenance. However, the acceptance test data do provide the benchmarks for the subsequent maintenance testing. The acceptance testing should be witnessed by the owner's representative, and a copy of the test reports forwarded to the plant engineer for his maintenance records.

Chapter 6 Substations and Switchgear Assemblies

6-1 Substations.

6-1.1 General.

6-1.1.1 Substations in an electrical system perform the functions of voltage transformation, metering and circuit switching, and system protection. They are comprised of electrical power products, such as transformers, regulators, air switches, circuit breakers, and lightning arresters.

6-1.1.2 Maintenance of the substation is of a general nature. Maintenance of the individual power products will be discussed under the appropriate heading.

6-1.1.3 The recommended frequency of maintenance will depend on the environment in which the substation is operating. In many cases it is an outdoor installation and exposed to the atmospheric contaminations in the neighborhood. In areas of industrial contamination or in coastal areas where ocean vapors are prevalent, inspections may be required at intervals of between six weeks and two months. Less frequent inspections may be required in areas of relatively clean atmosphere.

6-1.2 Insulators.

6-1.2.1 Insulators should be inspected for evidence of contaminated surfaces or physical damage, such as cracked or broken segments. Contaminated insulator surfaces should be cleaned and damaged insulators replaced.

6-1.2.2 Evidence of violent corona when the substation is energized should be reported. Corona is an electrical discharge phenomenon occurring in gaseous substances, such as air. High electrical gradients exceeding the breakdown level of air lead to corona discharges. Mild corona will have a low sizzling sound and may not be audible above ambient noise in the substation. As the corona increases in level, the sizzling sound becomes louder and will be accompanied by popping, spitting, or crackling as flashover level nears. Corona ionizes the air, converting the oxygen to ozone, which has a distinctive, penetrating odor.

6-1.2.3 Mild corona may be normal and will be more pronounced when humidity is high.

6-1.3 Conductors. Inspect all exposed conductors for evidence of overheating at bolted joints. Extreme overheating will discolor copper conductors. If the substation is de-energized, bolted connections should be checked for tightness. Bolts should be tightened where required, being careful not to overstress the bolts. There are infrared detectors that can be used on energized systems to check for overheating by scanning from a distance. Where aluminum-to-copper joints exist, inspect carefully for evidence of corrosion, overheating, or looseness.

6-1.4 Air-Disconnecting Switches.

6-1.4.1 Air-disconnecting switches are normally operated infrequently in service and will usually be energized during routine substation maintenance. In this case, maintenance of the switch will be limited to those areas that can be safely approached. The insulators and conducting parts should be examined as described earlier under these subjects. Interphase linkages and operating rods should be inspected to make sure that the linkage has not been bent or distorted and that all fastenings are secure. The position of the toggle latch of the switch operating linkage should be observed on all closed switches to verify that the switch is mechanically locked in a closed position.

6-1.4.2 Power-operated switches should be operated periodically to ensure that the switches and their mechanism and control features are functioning properly. When the circuit condition will not permit operating the switch while energized and the circuit cannot be de-energized for routine maintenance, the operating mechanism should be disengaged from the linkage to allow the control circuits and mechanism to be checked, provided that this method does not adversely affect the overall adjustment.

The maintenance instructions of the particular manufacturer of each mechanism should be followed. In addition, the following features should be checked: (1) limit switch adjustment; (2) associated relays for poor contacts, burned out coils, inadequate supply voltage; (3) any other condition that might prevent proper functioning of the switch assembly.

6-1.4.3 If the switches cannot be de-energized during routine maintenance, a scheduled outage should be planned periodically and thorough maintenance performed as follows:

(a) Operate the switch several times manually and check for approximate simultaneous closing of all blades and for complete contact closing. Check blade lock or latch in the fully closed position.

(b) If so equipped, the switch should be power operated and checked in accordance with the previously described procedure.

(c) Inspect contacts for alignment, pressure, burns, or corrosion. Replace pitted or badly burned contacts. If pitting is of a minor nature, smooth down the surface with clean, fine sandpaper. Inspect arcing horns for signs of excessive burning and replace, if necessary.

(d) Inspect insulation for breaks, cracks, or burns. Clean insulation where abnormal conditions, such as salt deposits, cement dust, or acid fumes, prevail.

(e) Check gear boxes for moisture that could cause corrosion or difficulty in the switch due to ice formation.

(f) Inspect flexible braids or slip-ring contacts commonly used for grounding the operating handle. Replace braids showing signs of corrosion, wear, or broken strands.

(g) Inspect and check all safety interlocks and test for proper operation.

6-1.4.4 If it is known that a switch has carried heavy short-circuit current, special effort should be made to inspect it at the earliest possible time, since the ability of the switch to carry rated load current or fault current may be seriously impaired if the contacts are not properly maintained.

6-1.5 Grounding Equipment. Inspect and test (where possible) all of the station grounds, enclosure grounds, and apparatus grounds. Inspect all grounding connections for tightness and absence of corrosion.

6-1.6 Enclosures. Check the security of fences or other enclosures to assure against entry of animals or unauthorized personnel. Check the gates or doors, especially when equipped with panic hardware, for security and proper operation. The enclosed area should not be used for storage of anything other than the most frequently used spare parts directly associated with the enclosed equipment.

6-1.7 Miscellaneous Equipment. Check the availability and condition of rack-out devices, hoisting or handling apparatus, grounding equipment, hot sticks, rubber gloves, statiscopes, and other test equipment.

Check for proper operation of floodlights and other auxiliary apparatus, such as cooling fans on transformers. Report any indication of warning lights or warning flags on temperature gauges, pressure gauges, or liquid level gauges.

6-2 Switchgear Assemblies.

6-2.1 General.

6-2.1.1 A switchgear assembly is an assembled equipment (indoor or outdoor) including but not limited to one or more of the following: switching, interrupting, control, metering, protective, and regulating devices, together with their supporting structure, enclosure, conductors, electric interconnections and accessories.

6-2.1.2 A switchgear assembly may be open type as part of a substation assembly or enclosed type. The open type was covered under the section on substations. This section will cover enclosed-type assemblies and, more specifically, metal-enclosed assemblies, since other types of enclosures are rarely found.

6-2.1.3 Metal-enclosed switchgear assemblies are enclosed on all sides and the top with sheet metal. Access into the enclosure is provided by doors or a removable cover. The bus and bus connections are bare in all except metal-clad-type switchgear assemblies. Although the bus and connections are insulated in metal-clad switchgear assemblies, THE INSULATION IS NOT DESIGNED TO PROTECT AGAINST ELECTRICAL SHOCK. CONTACT WITH THIS BUS OR ITS CONNECTIONS SHOULD BE AVOIDED WHEN THE SWITCHGEAR IS ENERGIZED.

6-2.1.4 Low-voltage metal-enclosed switchgear assemblies have a maximum nominal voltage rating of 600 volts. Medium- and high-voltage metal-enclosed switchgear assemblies have nominal voltage ratings from 5,000 to 69,000 volts inclusive.

6-2.1.5 These switchgear assemblies are normally constructed in modules or cubicles each of which contains either one or more interrupting devices (low-voltage cubicles usually contain two or more interrupting devices whereas medium- and high-voltage cubicles contain only one device) or auxiliary equipment, such as metering transformers, auxiliary power transformer, control relaying, battery chargers, etc. Power is fed throughout the assembly by the main power bus.

6-2.1.6 Metal-enclosed switchgear assemblies are normally connected to one or more supply transformers, either closely connected to the transformer throat or remotely connected by cable or metal-enclosed bus. They may be found outdoors as a part of a substation or indoors as a power distribution center.

6-2.2 Frequency of Maintenance.

6-2.2.1 Recommended frequency of maintenance will depend on environmental and operating conditions, so that no fixed rule can govern all applications.

An annual inspection of the entire switchgear assembly including withdrawable elements during the first three years of service is usually suggested as a minimum when no other criteria can be identified. Inspection frequency can be increased or decreased depending on observations and experience. It is good practice to follow specific manufacturer's recommendations regarding inspection and maintenance until sufficient knowledge is accumulated that permits modifying these practices based on experience. It is recommended that frequent inspections be made initially; the interval may then be gradually extended as conditions warrant.

6-2.2.2 The following factors will affect the decision on when to inspect:

(a) Scheduled shutdowns.

(b) Emergency shutdowns.

(c) Periods of sustained unusual or abnormal operating conditions, e.g., switching or lightning surges, sustained overloads.

(d) Feeder, bus, or system fault occurrence.

(e) Extremes in atmospheric conditions such as: heat, cold, heavy dust, high winds, rain, snow, fog, smog, fumes of many kinds, fly ash, salt spray, high humidity, unusual temperature changes, lightning, etc.

(f) Maintenance requirements and schedules for related equipment — either component parts of the switchgear assembly or items apart from but connected to the switchgear circuits. Time is the most universal criterion, but other indicators, such as number of operations, may be used as a guide.

6-2.2.3 Partial inspections may be made even when the entire switchgear assembly cannot be de-energized.

6-2.2.4 Specific circuits may be taken out of service even though the main bus is not de-energized. This permits an insulation inspection of bus risers and supports in the load side or "off" side of the switchgear unit.

6-2.2.5 When operating conditions are such that a full shutdown of an entire switchgear assembly for inspection of insulation is impractical, partial inspections may dictate a decision on whether or not a full shutdown is mandatory to avoid a potential developing failure. Conditions in those areas accessible for partial inspection, however, cannot be guaranteed to be indicative of conditions in areas not accessible for inspection under energized conditions.

6-2.3 Enclosure. The function of the enclosure is twofold: (1) prevent exposure of live parts and operating mechanisms, and (2) protect the equipment from exposure to moisture and air contaminants outside the enclosure. A good maintenance program will assure the continuation of these two functions.

6-2.4 Security. Inspect all doors and access panels to ensure that all hardware is in place and in good condition. Lubricate hinges, locks, and latches. Check for removal of screens from ventilation openings that may permit entry of rodents or small animals.

6-2.5 Leakage. On outdoor assemblies, check roof or wall seams for evidence of leakage and caulk any leaking seams. Although leakage may not be prevalent at time of inspection, prior leakage can be identified by rust or water marks on surfaces adjacent to and below leaky seams. Check around the base for openings that could permit water draining into the interior. Caulk or grout any such openings.

6-2.6 Moisture.

6-2.6.1 Moisture accumulation may occur on internal surfaces of enclosures even though they are weathertight. The source of this moisture is condensation. When the temperature of any surface drops below the dew point of the air with which it is in contact, condensation will occur. Humidity of outside atmosphere is not controllable as it enters the enclosure. However, water vapor can be added to the internal atmosphere if there are pools of water at the base of the enclosure in the vicinity of floor openings or bottom wall ventilation openings. All floor openings, other than those specifically provided for drainage purposes, should be effectively sealed. All unused conduits or openings around cables at entrance ducts should be sealed with an electrical grade of caulking compound. Water pools should be eliminated permanently.

6-2.6.2 Conditions causing condensation are intermittent and may not be prevalent at the time of inspection. All internal surfaces should be examined for signs of previous moisture such as:

(a) Droplet depressions or craters on heavily dust-laden surfaces.

(b) Dust patterns, such as those that occur if an auto is subjected to a light rain shower shortly after it has been driven on a dusty road.

(c) Deposit patterns, such as those that might occur if a film of dirty water was left to evaporate on a flat surface.

(d) Excessive rust anywhere on the metal housing.

6-2.6.3 Moisture accumulation is prevented by heat and air circulation. It is very important, therefore, to make sure the heating and ventilating systems are functioning properly.

6-2.7 Heating. Heat losses in switchgear assemblies carrying not less than 75 percent full load will probably prevent condensation except in those cubicles containing auxiliary equipment. Where space heaters are provided in each cubicle and in outdoor metal-enclosed bus runs to supply supplementary heat, they should be checked to ensure that they are in good condition and are operating properly. If they are thermostatically controlled, the thermostat should be checked for proper operation and setting. A thermostat set too low will not properly control the heaters under all climatic conditions.

6-2.8 Ventilation. Where ventilators are supplied on enclosures including metal-enclosed bus enclosures, check them to ensure that they are clear of obstructions and the air filters are clean and in good condition. Examine base foundations to ensure that structural members have not blocked floor ventilation.

6-2.9 Lighting and Housekeeping. Check all interior and exterior lighting for proper operation. Check availability of spare equipment and handling devices. They should be stored in such a manner as to be readily available yet not hamper normal manual operation or block ventilation passages.

6-2.10 Insulation.

6-2.10.1 With proper maintenance, the insulation of metal-enclosed switchgear assemblies is designed and expected to withstand operating voltages for periods of the order of 20 to 30 years. During this time, the insulation will be subject to an accumulation of deteriorating conditions that detract from its voltage withstanding capability.

6-2.10.2 Moisture combined with dirt is the greatest deteriorating factor for insulation. Perfectly dry dirt is mostly harmless, but even small amounts of moisture, such as condensation, will result in electrical leakage that leads to tracking and eventual flashover if allowed to continue to accumulate. It is important in the maintenance of switchgear to know the condition of the insulation. This is especially true in the older installations in unfavorable locations where deteriorating effects may be reaching significance.

6-2.10.3 The surfaces of all insulating members should be inspected before any cleaning or dust removal and repeated after cleaning. Moisture droplets often leave little craters or depressions in a heavy dust layer without staining the member under the dust. Conversely, a carbon track starting to form on a bus support sometime prior to inspection may be completely masked by later deposits of dust.

6-2.11 Electrical Distress. The following are specific areas in which electrical distress is more likely to occur and should be given special attention:

(a) Boundaries between two adjoining insulators.

(b) Boundaries between an insulating member and the grounded metal structure.

(c) Taped or compounded splices or junctions.

(d) Bridging paths across insulating surfaces, either phase-to-phase or phase-to-ground.

(e) Hidden surfaces such as the adjacent edges between the upper and lower member of split-type bus supports or the edges of a slot through which a busbar protrudes.

(f) Edges of insulation surrounding mounting hardware either grounded to the metal structure or floating within the insulating member.

Damage caused by electrical distress will normally be evident on the surface of insulating members in the form of corona erosion or markings or tracking paths.

6-2.12 Corona.

6-2.12.1 If corona occurs in switchgear assemblies, it is usually localized in thin air gaps that exist between a high-voltage busbar and its adjacent insulation or between two adjacent insulating members. It may form around bolt heads or other sharp projections if not properly insulated or shielded. Corona in low-voltage switchgear is practically nonexistent.

6-2.12.2 Organic insulating materials, when exposed to corona discharge, will initially develop white powdery deposits on their surface. These deposits can be wiped off with solvent. If the surface has not eroded, further maintenance is not required. Prolonged exposure to corona discharge will result in erosion of the surface of the insulating material. In some materials, corona deterioration has the appearance of worm-eaten wood. If the corrosion paths have not progressed to significant depths, surface repair can probably be accomplished. Manufacturer's recommendations should be followed in this repair.

6-2.13 Tracking.

6-2.13.1 Tracking is an electrical discharge phenomenon caused by electrical stress on insulation. This stress can occur phase-to-phase or phase-to-ground. Although tracking can occur internally in certain insulating materials, these materials as a rule are not used in medium- or high-voltage switchgear insulation. Tracking, when it occurs in switchgear assemblies, will normally be found on insulation surfaces.

6-2.13.2 Tracking develops in the form of streamers or sputter arcs on the surface of insulation usually adjacent to high-voltage electrodes. One or more irregular carbon lines in the shape of tree branches is the most common sign of tracking.

6-2.13.3 Surface tracking can occur on the surfaces of organic insulation or on contaminated surfaces of inorganic insulation. The signs of tracking on organic materials are eroded surfaces with carbon lines. On track-resistant organic materials these erosion patterns will be essentially free of carbon.

Tracking can propagate from either the high-voltage or ground terminal. It will not necessarily progress in a regular pattern or by the shortest possible path.

6-2.13.4 Tracking conditions on surfaces of inorganic material can be completely removed by cleaning its surfaces since no actual damage to the material occurs. In the case of organic material, the surface is damaged in varying degrees depending on the intensity of the electric discharge and the duration of exposure. If the damage is not too severe, it can be repaired by sanding and application of track-resistant varnish in accordance with the manufacturers' instructions.

6-2.14 Thermal Damage.

6-2.14.1 Temperatures, even slightly over design levels for prolonged periods, can significantly shorten the electrical life of organic insulating materials. Prolonged exposure to higher than rated temperatures can cause physical deterioration of these materials resulting in lower mechanical strength.

6-2.14.2 Localized heating (hot spots) can sometimes occur but be masked because the overall temperature of the surroundings is not raised appreciably. Loosely bolted connections in a busbar splice or void spaces (dead air) in a taped assembly are examples of this.

6-2.14.3 Since power should be removed prior to inspection, it is relatively unlikely that temperature itself can be relied on to signal potentially damaging heat. Other external conditions, therefore, form the basis for detecting heat damage:

(a) Discoloration — usually a darkening — of materials or finishes.

(b) Crazing, cracking, flaking of varnish coatings.

(c) Embrittlement of tapes and cable insulation.

(d) Delamination.

(e) Generalized carbonization of materials or finishes.

(f) Melting, oozing, or exuding of substances from within an insulating assembly.

Insulating materials that have been physically damaged should be replaced. Mild discoloration is permissible if the cause of overheating is corrected. In summary, there are two important things to remember in maintenance of insulation. KEEP IT CLEAN and KEEP IT DRY.

6-3 Circuit Interrupters. Circuit interrupters in switchgear assemblies are either circuit breakers or interrupter switches. Fuses are technically interrupters, but they will be covered as an item of auxiliary equipment.

6-4 Air Circuit Breakers.

6-4.1 General.

6-4.1.1 Before any maintenance work is performed, manufacturer's instruction manuals should be obtained and read carefully. If it is a drawout-type breaker, it should be removed from its cubicle and placed in a secure, convenient location for maintenance. A stored energy-type circuit breaker or its mechanism should never be worked on while its closing spring is charged.

6-4.1.2 Maintenance on fixed- or bolted-type circuit breakers is normally performed with the breaker in place inside its cubicle. Special precaution must therefore be exercised to assure that the equipment is de-energized and the circuit in which it is connected is properly secured from a safety standpoint. All control circuits should be de-energized. Stored energy closing mechanisms should be discharged.

Maintenance operations on air circuit breakers can be broken down into five categories as follows:

6-4.2 Insulation. Remove interphase barriers and clean them and all other insulating surfaces with dry compressed air — a vacuum cleaner, or clean lint-free rags and solvents as recommended by the manufacturer, if needed, to remove hardened or encrusted contamination. Inspect for signs of corona, tracking, or thermal damage as described in 6-2.10 through 6-2.14. The maintenance theme here again is KEEP IT CLEAN and KEEP IT DRY.

6-4.3 Contacts.

6-4.3.1 General. The major function of the air circuit breaker depends among other things on correct operation of its contacts. These circuit breakers normally have at least two distinct sets of contacts on each pole, main and arcing. Some have an intermediate pair of contacts that open after the main current carrying contacts and before the arcing contacts. When closed, practically the entire load current passes through the main contacts. Also, high overload or short circuit current must pass through them during opening or closing faulted lines. If the resistance of these contacts becomes high, they will overheat. Increased contact resistance can be caused by pitted contact surfaces, foreign material embedded on contact surfaces, or weakened contact spring pressure. This will cause excessive current to be diverted through the arcing contacts, with consequent overheating and burning.

Keep the pressure "normal," which is usually described in the manufacturer's instructions.

6-4.3.2 Arcing contacts are the last to open; any arcing normally originates on them. In circuit interruption, they carry current only momentarily, but that current may be equal to the interrupting rating of the breaker. In closing against a short circuit, they may momentarily carry considerably more than the short-circuit-interrupting rating. Therefore, they must make positive contact when they are touching. If not, the main contacts can be badly burned interrupting heavy faults; failure to interrupt may also result.

On magnetic blow-out air breakers, the arc is quickly removed from the arcing contacts by a magnetic "blow-out" field and travels to arcing horns, or "runners," in the arc interrupter. The arcing contacts are expendable and will eventually burn enough to require replacement.

6-4.3.3 The general rules for maintaining contacts on all types of breakers are:

(a) Keep them clean, smooth, and in good alignment.

(b) Keep the pressure normal as prescribed in manufacturer's literature.

6-4.3.4 The main contact surfaces should be clean and bright. However, discoloration of the silvered surfaces is not usually harmful unless caused by insulating deposits. These should be removed with alcohol or a silver cleaner. Slight impressions on the stationary contacts will be caused by the pressure and wiping action of the movable contacts. Minor burrs or pitting can be allowed and projecting burrs may be removed by dressing. Nothing more abrasive than crocus cloth should be used on the silvered contact surfaces. Where serious overheating is indicated by discoloration of metal and surrounding insulation, the contacts and spring assemblies should be replaced in line with manufacturer's instructions.

6-4.3.5 Manually close the circuit breaker to check for proper wipe, pressure, contact alignment, and to assure that all contacts make at approximately the same time. Check the spacing between stationary and movable contacts in the fully open position. Make adjustments in accordance with manufacturer's recommendations.

6-4.3.6 Laminated copper or brush-style contacts found on older circuit breakers should be replaced when badly burned. Repairs are not practical because the laminations tend to weld together when burning occurs, and contact pressure and wipe are greatly reduced. They may be dressed with a file to remove burrs or to restore their original shape. They should be replaced when they are burned sufficiently to prevent adequate circuit breaker operation or when half of the contact surface is burned away. Carbon contacts, used on older circuit breakers, require very little maintenance. However, inadequate contact pressure caused by erosion or repeated dressing may cause overheating or interfere with their function as arcing contacts.

6-4.3.7 The drawout contacts on the circuit breaker and the stationary contacts in the cubicle should be cleaned and inspected for overheating, proper alignment, and broken or weak springs. The contact surfaces should be lightly coated with a contact lubricant to facilitate ease of the mating operation.

6-4.4 Arc Interrupters.

6-4.4.1 General. Modern arc interrupters of medium-voltage magnetic blow-out air circuit breakers are built with only inorganic materials exposed to the arc. Such materials line the throats of the interrupter and constitute the interrupter plates or fins which act to cool and disperse the arc. The insulation parts of the interrupter remain in the circuit across contacts at all times. During the time that the contacts are open, these insulating parts are subject to full potential across the breaker. Ability to withstand this potential depends on the care given the insulation.

6-4.4.2 Particular care should be made at all times to keep the interrupter assembly dry. The materials are not much affected by humidity, but the ceramic material especially will absorb water.

6-4.4.3 On general inspections, blow out the interrupters with dry compressed air by directing the air upward from the contact area and out through each of the slots between the arc splitter plates. Also direct the dry air stream thoroughly over the arc shields. These are the ceramic liners in the lower end of the interrupter where the arc is drawn.

6-4.4.4 The interrupters should be inspected each time the contacts are inspected. Remove any residue, dirt, or arc products with a cloth or by a light sanding. Do not use a wire brush or emery cloth for this purpose because of the possibility of embedding conducting particles in the ceramic material.

6-4.4.5 When inspecting an interrupter, look for the following:

(a) *Broken or Cracked Ceramic Parts.* Small pieces broken from the ceramics or small cracks are not important. But large breaks or expansive cracks may interfere with top performance of the interrupter. Hence if more than one or two broken or badly cracked plates are apparent, renewal of the ceramic stack is indicated.

(b) *Erosion of Ceramics.* When an arc strikes a ceramic part in the interrupter, the surface of the ceramic will be melted slightly. When solidified again, the surface will have a glazed whitish appearance. At low and medium currents, this effect is very slight. However, large current arcs repeated many times may boil away appreciable amounts of the ceramic. When this happens, the ceramic stack assembly should be replaced.

(c) *Dirt in Interrupter.* In service, the arc chute assembly will become dirty from three causes. First, dust deposited from the air that can readily be blown out of the chute with a dry compressed air stream. Second, loose soot deposited on the inside surfaces of the arc chute in the lower portions near the contacts that may be removed by wiping with cloths free of grease or metallic particles. The third is very tightly adhering deposits from the arc gases on the ceramic arc shields near the contacts. These deposits, from the metal vapors boiled out of the contacts and arc horns, may accumulate to a harmful amount in breakers that receive many operations at low- or medium-interrupting currents. Particular attention should be paid to any dirt on the plastic surfaces below the ceramic arc shield. Wipe clean if possible. If wiping will not remove the dirt, clean with sandpaper to remove all traces of carbon or metallic deposit. On breakers that operate thousands of times at low and medium currents, tightly adhering dirt may accumulate on the ceramic arc shields sufficiently to impair proper interrupting performance. These arc shields are of a very hard material, and a hard nonconducting abrasive is necessary for cleaning. The best and easiest way to clean them is by nonconductive sand blasting, NOT SHOT BLASTING. Next best is a flexible abrasive disc on an electric drill with medium grain aluminum oxide discs.

The ceramic arc shields may appear dirty and yet have sufficient dielectric strength. The following insulation test may be used as a guide in determining when this complete or major cleaning operation is required. The arc chutes of medium-voltage circuit breakers should withstand the 60 Hz rated maximum voltage for one minute between the front and rear arc horns. In some applications, circuit breakers may be exposed to over-voltages, in which case such circuit breakers should have an appropriate over potential test applied across the open contacts.

(d) Some manufacturers also recommend a surface dielectric test of the ceramic surfaces near the contacts to verify adequate dielectric strength of these surfaces.

6-4.4.6 Air puffer devices used to blow the arc up into the interrupter should be checked for proper operation. One accepted method is with the interrupter mounted on the breaker in its normal position. Place a piece of tissue paper over the discharge area of the interrupter and observe for movement when the breaker is opened. Any perceptible movement of the paper indicates that the puffer is functioning properly.

6-4.4.7 Low-voltage air circuit breaker arc chutes are of relatively simple construction, consisting primarily of a wedge-shaped vertical stack of "SPLITTER" plates enclosed in an insulating jacket. An arc chute is mounted on each pole unit directly above the main contacts. Arc interruptions produce erosion of the "splitter" plates. The lower inside surfaces of the insulating jackets will also experience some erosion and sooty discoloration.

The arc chutes should be removed and examined as part of routine maintenance. If the "splitter" plates are seriously eroded, they should be replaced. If the interior surfaces of the enclosing jackets are discolored or contaminated with arc products, they should be sanded with sandpaper or replaced. Occasionally the whole arc chute may need replacing depending upon the severity of the duty.

6-4.5 Operating Mechanism.

6-4.5.1 General. The purpose of the operating mechanism is to open and close the contacts. This usually is done by linkages connected, for most power breakers, to a power operating device such as a solenoid or closing spring for closing, and which contains one or more small solenoids or other types of electromagnets for tripping. Tripping is accomplished mechanically independently from the closing device, so that the breaker contacts will open even though the closing device still may be in the closed position. This combination is called a mechanically trip-free mechanism. After closing, the primary function of the operating mechanism is to open the breaker when it is desired, which is whenever the tripping coil is energized at above its rated minimum operating voltage.

6-4.5.2 The operating mechanism should be inspected for loose or broken parts; missing cotter pins or retaining keepers; missing nuts and bolts; and for binding or excessive wear. All moving parts are subject to wear. Long-wearing and corrosion-resistant materials are used by manufacturers, and some wear can be tolerated before improper operation occurs.

Excessive wear usually results in loss of travel of the breaker contacts. It can affect operation of latches; they may stick or slip off and prematurely trip the breaker. Adjustments for wear are provided in certain parts. In others, replacement is required.

The closing and tripping action should be quick and positive. Any binding, slow action, delay in operation, or failure to trip or latch must be corrected prior to returning to service.

6-4.5.3 The two keepers to apply in maintenance of the operating mechanism are KEEP IT SNUG and KEEP IT FRICTION FREE.

6-4.6 Breaker Auxiliary Devices.

6-4.6.1 Inspect the closing motor or solenoid, shunt trip, auxiliary switches, and bell alarm switch for correct operation, insulation condition, and tightness of connections.

6-4.6.2 Check on-off indicators, spring-charge indicators, mechanical and electrical interlocks, key interlocks, and padlocking fixtures for proper operation, and lubricate where required. In particular, test the positive interlock feature that prevents the insertion and withdrawal of the circuit breaker while it is in the closed position.

6-4.6.3 The protective relay circuits should be checked by closing the breaker in the test position and manually closing the contacts of each protective relay to trip the circuit breaker. Test procedures are given in 18-10.3.

6-4.6.4 Trip devices on low-voltage breakers may be the electromechanical series overcurrent type with an air or fluid dashpot for time delay. These devices should be periodically tested for proper calibration and operation with low-voltage/high-current test devices. Calibration tests should be made to verify that the performance of the breaker is within the manufacturer's published curves. It is very important that manufacturer's calibration curves for each specific breaker rating be used and to take into account that current-time curves are plotted as a band of values rather than a single line curve. It should be realized that short-time calibration cannot be checked accurately because factory calibration equipment has synchronized timing devices to ensure symmetrical currents whereas field test equipment features random closing and may produce asymmetrical currents resulting in faulty readings. If the trip devices do not operate properly, the calibration and timing components should be repaired or replaced in line with the manufacturer's recommendations.

6-4.6.5 If the breakers are equipped with static-tripping devices, they should be checked for proper operation and timing in line with the manufacturer's recommendations. Some manufacturers recommend replacement of electromagnetic devices with static devices in the interest of realizing more precision and a higher degree of reliability with the latter devices.

6-5 Vacuum Circuit Breakers.

6-5.1 The principal difference between vacuum circuit breakers and air circuit breakers is in the main contact and interrupter equipment. In the vacuum circuit breaker, these components are in the vacuum bottle and are not available for cleaning, repair, or adjustment. Contact wear indicators are available for measuring contact wear.

6-5.2 Vacuum integrity is checked by application of test voltage across the open contacts of the bottle. This test must be performed strictly in accordance with the manufacturer's instructions. APPLICATION OF HIGH VOLTAGE ACROSS AN OPEN GAP IN VACUUM MAY PRODUCE X-RAY EMISSION.

The level of X-ray emission from a vacuum breaker with proper contact spacing and subjected to standard test voltages is extremely small and well below maximum level permitted by standards. In view of the possibility that the contacts are out of adjustment or that the applied voltage is greater than prescribed, it is advisable that during the overvoltage test, all personnel stand behind the front steel barrier and remain further from the breaker than would otherwise be necessary for reasons of electrical safety. During this high-voltage test, the vapor shield inside the interrupter can acquire an electrostatic charge. This charge should be bled off immediately after the test.

6-5.3 All other maintenance on vacuum circuit breakers should be performed in accordance with that recommended on air circuit breakers.

6-6 Oil Circuit Breakers.

6-6.1 General.

6-6.1.1 Oil circuit breakers are seldom found in modern metal-enclosed switchgear assemblies. They are prevalent in older metal-enclosed switchgear assemblies and in open-type outdoor substations.

6-6.1.2 Although oil circuit breakers perform the same function in switchgear assemblies as air circuit breakers, they are quite different in appearance and mechanical construction. The principal insulating medium is oil rather than air.

6-6.2 Insulation.

6-6.2.1 External insulation is provided by insulating bushings. Outdoor oil circuit breakers have porcelain bushings, whereas indoor breakers may have either porcelain bushings or organic tubing. The bushings should be examined for evidence of damage or surface contamination. If they are damaged to the extent that the electrical creepage path has been reduced or the glazed surface on porcelain bushings damaged, they should be replaced. Otherwise they should be cleaned thoroughly as required to remove all surface contamination.

6-6.2.2 The oil, in addition to providing insulation, also acts as an arc-extinguishing medium in current interrupters. In this process, it absorbs arc products and experiences some decomposition in the process. Thus, maintenance of the oil is of great importance. It involves detection and correction of any condition of the oil that would lower its quality. The principal contaminants are moisture, carbon, and sludge. Moisture will appear as droplets on horizontal members, while free water will accumulate in the bottom of the tank. Sludge caused by oxidation will appear as a milky translucent substance. Carbon initially appears as a black trace. It eventually will disperse and go into suspension causing the oil to darken.

6-6.2.3 A dielectric breakdown test is a positive method of determining the insulating value of the oil. Samples may be taken and tested as covered in ASTM D877 and as outlined in 7-2.8.2 and 7-2.8.6. Oil that tests too low should be immediately reconditioned and retested or replaced with new oil. Oil should be tested periodically or following a fault interruption.

6-6.2.4 In replacing the oil, use only the oil recommended by the manufacturer and that has been stored in sealed containers. In addition, the oil should be given a dielectric breakdown test immediately prior to use. Avoid air entrapment when adding oil by using an oil pump or other means to avoid aeration. In the event entrapment of air cannot be avoided, the entrapped air should be removed by application of vacuum or the equipment should be allowed to stand for 8 to 12 hours prior to being energized.

6-6.3 Contacts. The main contacts of an oil circuit breaker are not readily accessible for routine inspection. Contact resistance should be measured. Contact engagement can be measured by measuring the travel of the lift rod from the start of contact opening to the point where contacts separate as indicated by an ohmmeter.

More extensive maintenance on main contacts will require removal of the oil and lowering the tank, and will therefore be performed less frequently than routine maintenance. The frequency will be determined by the severity of the breaker duty such as the number of operations and operating current levels. Any time the breaker has interrupted a fault current at or near its maximum rating, this type of maintenance should be performed. The contacts should be inspected for erosion or pitting. Contact pressures and alignment should be checked. All bolted connections and contact springs should be inspected for looseness.

6-6.4 Arc-Quenching Assemblies. Arc-quenching assemblies should be inspected for carbon deposits or other surface contamination in the areas of arc interruption. If cleaning of these surfaces is necessary, manufacturer's instructions should be followed.

6-6.5 Operating Mechanism. Maintenance of the operating mechanism should follow the same procedure as recommended for air circuit breakers (*see 6-4.5*).

6-6.6 Breaker Auxiliary Devices. Breaker auxiliary devices maintenance should follow the same procedure as recommended for air circuit breakers (*see 6-4.6*) when applicable. Inspect other accessories such as oil level gauges, sight glasses, valves, gaskets, breathers, oil lines, and tank lifters. The breaker should be taken out of service immediately if the oil level is below the level gauge or sight glass.

6-7 Interrupter Switches.

6-7.1 A medium-voltage interrupter switch is an air switch equipped with an interrupter for making or breaking specified currents or both. It may be either the fixed mounted or drawout type and may be either manually or electrically operated. If fixed mounted, they will be interlocked with access doors or panels to prevent access to closed switches.

6-7.2 Maintenance procedures should correspond to those recommended for air circuit breakers except as regards the interrupter device. This device, on most interrupter switches, is of very simple open-type construction and can be easily inspected and cleaned without removal from the switch. Enclosed interrupters must be removed from the switch and disassembled for maintenance in accordance with the manufacturer's recommendation. Dielectric tests are not required as a part of maintenance. Air puffers are not employed in this type of interrupter.

6-8 Auxiliary Equipment.

6-8.1 Fuses. Fuse maintenance is covered as a separate category of electrical equipment in Chapter 13.

6-8.2 Surge Arresters.

6-8.2.1 Surge arresters should be inspected periodically for evidence of damage to the porcelain housing or surface contamination. If the porcelain is damaged to the extent that the creepage path over its surface is reduced or the porcelain glazed surface is seriously damaged, the arrester should be replaced. Otherwise, the porcelain surface should be cleaned thoroughly as required to remove all surface contamination.

6-8.2.2 There are no simple practical field tests that will determine the complete protective characteristics of lightning arresters. There are, however, certain tests that can be made with apparatus usually available that will give sufficient information to determine whether the arrester can be relied on to be an insulator under normal conditions. These tests are: 60 cycle spark-over and hold tests, watts-loss and leakage-current tests, insulation resistance, and grounding-electrode circuit-resistance tests. These tests must be done strictly in accordance with manufacturer's recommendations and the results interpreted in line with manufacturer's criteria.

6-8.3 Capacitors.

6-8.3.1 Always discharge capacitors before handling or making connections by closing the ground devices that are usually installed with large capacitor banks. An insulated short-circuit jumper may be used for dissipating the charge; however, it should only be applied with full knowledge of the circuit, and with the use of appropriate protective equipment.

6-8.3.2 Caution: Capacitors, even though they have discharge resistors, may possess a stored charge capable of injuring a person coming into contact with the terminals.

6-8.3.3 Clean the capacitor case, the insulating bushings, and any connections that are dirty or corroded. Inspect each capacitor case for leaks, bulges, or discoloration. Replace any liquid-filled capacitor found to be bulging or leaking. (*Refer to section on liquid-filled transformers, Section 7-2.*)

6-8.3.4 Power capacitors are generally provided with individual fuses to protect the system in case of a short circuit within the capacitor. In addition to a faulty capacitor, a fuse can also be blown by an abnormal voltage surge. Check for blown fuses and replace with the type recommended by the manufacturer. Do not remove fuses by hand until the capacitor has been completely discharged.

6-8.3.5 Adequate ventilation is necessary to remove the heat generated by continuous full-load duty. Remove any obstructions at ventilation openings in capacitor housings, and ensure that adequate ventilation is provided and maintained.

6-8.4 Lead-Acid Storage Batteries and Battery Chargers.

6-8.4.1 General. The control battery is such an important item in switchgear operation that it must be given strict attention in the maintenance program. The battery charger plays a critical role since it supplies normal dc requirements to the station and maintains the batteries at a high level of charge. The batteries, in addition to supplying temporary heavy demands in excess of the charger capacity, serve as a standby source to trip breakers upon loss of ac power. Failure of the charger or its ac supply transfers all dc load to the batteries.

6-8.4.2 Batteries should be inspected for proper level and proper specific gravity of the electrolyte. Low specific gravity readings indicate a low state of charge. If the readings between cells vary more than fifty points on the hydrometer scale, the battery probably has a bad cell and should be replaced. If all cells read consistently low (within 50 points), the battery should be fully charged and the battery charger checked for proper operation. Low electrolyte level may indicate too high a charging rate. In this case, the "float-voltage" setting of the charger should be checked against the battery manufacturer's recommendations for the specific battery.

6-8.4.3 The battery top surface should be clean. Surface contamination can produce leakage currents that present a drain on the charger and the battery. Battery terminal connectors should be tight and free of corrosion. If the terminal connectors are corroded, they should be removed and cleaned thoroughly with bicarbonate of soda. Battery studs and cable ends should be cleaned thoroughly. If stranded cable is used, it is advisable to cut off the corroded end. If this is not possible, the strands should be separated and cleaned internally.

6-8.4.4 Any dust accumulation on the battery charger should be blown off or wiped clean. Ventilation openings should be clear of obstructions. Terminal connections should be checked for tightness. All relays, lights, or horns for indicating such abnormal conditions as grounds, loss of ac power supply, and high or low voltage should be checked to ensure that they are operating properly.

6-8.4.5 During maintenance outages of the ac supply, there may be times when it is necessary to provide a temporary supply to the charger.

6-8.4.6 Safety. While being charged, a battery produces and emits a mixture of hydrogen and oxygen gases that is very explosive. Open flames or sparks must not be permitted in close proximity to the batteries. The room or compartment in which operating batteries are located should be well ventilated. Smoking should be prohibited in these rooms or compartments.

6-8.5 Instrument Transformers and Auxiliary Transformers.

6-8.5.1 Instrument transformers and auxiliary transformers may be the outdoor type, although in some cases they may be mounted inside metal-enclosed switchgear assemblies. These transformers are similar to other outdoor transformers in that they are liquid filled and equipped with outdoor bushings. All recommendations for maintenance of outdoor transformers, therefore, apply.

6-8.5.2 Indoor-type instrument and auxiliary transformers are normally dry type, except that potential transformers may be enclosed in compound-filled metal cases. Common construction for all of these transformers have the complete transformer except its terminals molded into one solid mass with only the terminals exposed. Maintenance recommendations for these indoor transformer types are the same as those for metal-enclosed switchgear assemblies insulation (*see 6-2.10*). The same conditions of environment and electrical and thermal distress prevail. In other words KEEP THEM CLEAN and KEEP THEM DRY.

6-8.6 Alarm and Indicators.

6-8.6.1 Alarms. Alarms associated with transformer overtemperature, high or low pressure, circuit breaker trip, accidental ground on an ungrounded system, cooling waterflow or overtemperature, or other system conditions should be tested periodically to assure proper operation.

6-8.6.2 Indicators. Circuit breaker "open-close" indicators can be checked during their regular maintenance. Ground indicator lamps for ungrounded electric systems should be checked daily or weekly for proper operation. Other miscellaneous indicators such as flow, overtemperature, excess pressure, etc., should be checked or operated periodically to assure proper operation.

6-8.7 Protective Relays, Meters, and Instruments.

6-8.7.1 Caution. The current elements of these devices are usually connected in the secondary circuit of current transformers. Opening the secondary circuit of an energized current transformer will produce a very high voltage that can be fatal. Therefore, the secondary terminals of an energized current transformer must be short-circuited before opening the secondary circuit. Some relays and instruments have special test terminals or test switches that make a closed circuit in the C.T. secondaries during test. Upon completion of tests, it is necessary to remove the short-circuit jumper to permit the C.T. to function.

6-8.7.2 Since protective relays and instruments play such an important role in the prevention of hazard to personnel and plant equipment, they should be given first line maintenance attention. Furthermore, since the only time they operate is during an abnormal electric power system condition, the only way to assure correct operation is by a comprehensive inspection, maintenance, and testing program.

6-8.7.3 Examine meters, instruments, and relays to ensure that all moving parts are free of friction or binding. Check wiring for loose connections. Inspect contacts for pitting or erosion. Look for evidence of overheating in solenoid coils or armatures. Replace cracked glass or damaged covers or cases. See 18-10.3 for testing recommendations.

6-8.8 Interlocks and Safety Devices. Interlocks and safety devices are employed for the protection of personnel and equipment and should, therefore, never be made inoperative or bypassed. Proper functions of these devices should be ensured by the following procedures:

(a) These devices are designed for protection of personnel and equipment. They should never be disconnected or bypassed.

(b) Check the adjustments and operation of the devices as follows:

1. Mechanical interlocks on drawout mechanisms must prevent withdrawal or insertion of circuit breakers in the closed position.

2. Safety shutters, where provided, should automatically cover the "stab-in" ports.

3. Limit switches should prevent overtravel of motorized lifting devices.

(c) Operate key interlock systems in proper sequence, and check for suitable operation. Make adjustments and lubricate as necessary. Instructions should be posted on complicated systems, especially where the interlocks may only be operated annually or in emergencies.

(d) Spare keys should be identified and stored in the custody of the supervisor.

(e) Grounding switches used in medium-voltage switchgear should be maintained to the same degree as the circuit breaker itself. If they are stored indoors, they should be covered to prevent dust accumulation. If stored outdoors, they should be stored in a weatherproof covering.

6-8.9 Equipment Grounding.

6-8.9.1 Equipment grounding circuits are not inherently self-monitoring as are circuits that normally carry current. To ensure that the equipment grounding circuit continues to be effective when called upon to carry ground-fault current, it should be checked periodically.

6-8.9.2 Checking a system to determine the adequacy of the equipment ground involves inspection of connections that can be supplemented by an impedance test to enable an evaluation of those parts of the system not accessible for inspection. Refer to Section 18-13.

6-8.9.3 Terminal connections of all grounding conductors and bonding jumpers should be checked to see that they are tight and free of corrosion. Bonding jumpers should also be examined for physical abuse, and those with broken strands should be replaced. Where metal raceway is used as the equipment grounding path, couplings, bushings, setscrews, and locknuts should be checked to see that they are tight and properly seated. Any metal raceway used as the equipment grounding path should be examined carefully for rigid mounting and secure joints; screws and bolts should be retightened.

6-8.10 Ground Detectors.

6-8.10.1 Ground detectors may be installed on all ungrounded or resistance-grounded low-voltage systems. The detector may consist of a simple set of lamps wired phase-to-ground. A ground on one phase will cause the lamp on that phase to be dark, while the other two lamps will have increased brilliancy.

6-8.10.2 A more elaborate system provides audible as well as visual indication so the ground is more readily detected.

6-8.10.3 Once a ground has been detected, prompt location and correction are important since the system is now highly vulnerable in the event of a ground on another phase. The isolation method of searching for the ground requires circuit or system outages until the ground is located and eliminated. The use of an instrument that permits location of such grounds without power outages is recommended.

6-8.10.4 Maintenance of ground detectors should include a complete inspection of the signal elements such as lamps, horns, or buzzers. Audible devices should be operated to ensure that they are in operable condition. Wiring should be checked for loose connections or damaged wiring.

Summary: A complete, effective maintenance program for substations and assembled switchgear will result if the four KEEPERS are observed:

If it's insulation: KEEP IT CLEAN and KEEP IT DRY.

If it's mechanical: KEEP IT SNUG and KEEP IT FRICTION FREE.

6-8.11 Network Protectors.

6-8.11.1 A network protector is an air circuit breaker equipped with specialized relays that sense network circuit conditions and command the circuit breaker to either open or close. There is no separate power source for control. All control power is taken from the system.

A routine maintenance schedule for network protectors should be observed. Frequency of inspection will vary to a great extent on location and environment in which a protector is installed.

Maintenance should include cleaning any accumulation of dust from unit, a thorough visual inspection, and overall operational test. Should any part look suspicious, refer to manufacturer's instructions describing operation, adjustment, and replacement of these parts. If relays are out of calibration, they should be recalibrated by competent personnel.

6-8.11.2 Safety. Network protectors are used where a large amount of power is distributed to high load density areas. As a result, any short circuit at any point in the system involves very high fault currents. Due to the nature of a secondary network, some maintenance must be performed while the system is energized. In this work ALWAYS USE INSULATED TOOLS AND WEAR SAFETY GLOVES. RIGID CLEARANCE PROCEDURES MUST BE OBSERVED. Extensive use of barriers has been a salient feature in the design of this equipment. Keep these barriers in place and immediately replace any that have been broken. Only skilled maintenance personnel thoroughly familiar with the construction and operation of network protectors should be permitted to perform any maintenance on an energized unit. The first procedure in performing maintenance is TRIP THE PROTECTOR TO THE OPEN POSITION.

6-8.11.3 Maintenance. The circuit breaker mechanism and relay panel assembly are usually constructed as an integral drawout unit that should be withdrawn from the housing for maintenance. Removal of the fuses at the top and the disconnecting links at the bottom (some modern protectors have bolt-actuated disconnecting fingers at the bottom) isolates the unit electrically from the system. Although this provides comparative safety, work should be done cautiously since it may be assumed that normally there is voltage on the transformer and the network leads. With the drawout unit outside the enclosure on the extension rails, perform the following inspection and maintenance operations on the drawout unit: [Item (k) applies only to the containing structure — not the drawout unit.]

(a) Clean complete unit. Use of a vacuum-type cleaner is preferred. Use cloth rags free of oil or greases for removing clinging dirt.

(b) Remove arc chutes. Replace any broken splitter plates.

(c) Inspect main contacts. Smooth any heavily frosted area with a fine file, stone, crocus cloth, or other suitable abrasive that does not shed abrasive particles. Protect hinge joint from falling particles during dressing.

(d) During normal operation, arcing contacts become rough due to arcing. Any especially high projections of metal should be filed smooth.

(e) See that all electrical connections are tight.

(f) Look for any abrasion of wire insulation.

(g) Check for overheating of control wire and current carrying parts.

(h) See that all springs are in place and not broken.

(i) See that all nuts, pins, snap rings, and screws are in place and tight.

(j) Replace any broken barriers.

(k) With the rollout unit removed, perform the following maintenance operations inside the enclosure:

AS MENTIONED ABOVE, BOTH NETWORK AND TRANSFORMER CONNECTIONS SHOULD BE TREATED AS THOUGH THEY ARE ENERGIZED. WHEN WORKING IN HOUSING OR ON FRAME USE ONLY INSULATED TOOLS AND WEAR SAFETY PROTECTIVE EQUIPMENT. DO NOT REMOVE ANY BARRIERS FROM ENCLOSURE.

1. Look for loose hardware on the floor or beneath the frame. If any is found, trace to source.

2. Clean stand-off bus insulators.

3. Remove any oxide film from terminal contacts if necessary.

(l) Manually close protector in accordance with the manufacturer's instructions. It should close with a definite snap action. Sluggish closing indicates excessive friction. Move trip level to "tripped" position. Breaker should snap open.

(m) An operational test is best performed using a network protector test kit.

(n) Perform an insulation resistance test, dielectric test, and electrical operating tests strictly in accordance with the manufacturer's recommendations.

Chapter 7 Power and Distribution Transformers

7-1 General.

7-1.1 A transformer is a device for changing energy in an alternating current system from one voltage to another. It usually includes two or more insulated coils on an iron core.

7-1.2 In industrial installations, transformers are usually used to transform or step down a higher distribution level voltage to a lower utilization level. They are vital links in electrical power systems and are among the most reliable components in the system. If they are not overloaded or otherwise abused, they should provide long, trouble-free service. Established records of reliable performance, coupled with a lack of movement, noise, or other sign of action, often result in general disregard and neglect. Because a transformer failure is usually of a very serious nature, requiring extensive repair and long downtime, regular maintenance procedures are the best assurance of continued high reliability.

7-1.3 Power transformers are defined as those larger than 500 kVA, while distribution transformers are those 500 kVA or smaller. Both types require regular maintenance if they are to have a normal service life. The extent and frequency of maintenance should be based not only on size or voltage but also on the relative importance of the transformer in the system. The failure of a small distribution transformer serving a critical load can have more impact on an operation than the failure of a larger or higher voltage unit. Also, on some smaller systems, the failure of a distribution transformer can result in an outage of the complete system. When planning the level of maintenance on a transformer, consideration should also be given to other factors, such as replacement lead time.

7-1.4 Transformers may be divided into two general categories in accordance with their insulating medium and construction: liquid filled and dry type. Each has several variations listed under the specific maintenance recommendations, and each requires different maintenance techniques. In general, insulation tests, such as power factor testing and insulation-resistance testing, and diagnostic tests, such as turns-ratio testing and exciting-current testing, are the major maintenance tests for all transformers. In addition, liquid-filled transformers should be tested to determine the quality of the insulating liquid.

7-2 Liquid-filled Transformers.

7-2.1 General.

7-2.1.1 The core and coils of liquid-filled transformers are immersed in a liquid. The liquid serves two purposes. It is an important part of the insulating medium; and it serves to transfer heat away from the windings to be dissipated by the cooling fins, tank surface, or radiator.

7-2.1.2 Two types of insulating liquid in common use are mineral-insulating oil and askarel. Other types of liquids used are less-flammable liquids, such as silicone or stabilized hydrocarbon liquids. Each liquid has definite characteristics and THEY SHOULD NOT BE MIXED. Manufacturers' instructions should be carefully followed with all insulating liquids.

7-2.1.3 Askarel is identified by various brand names and consists largely of polychlorinated biphenyls (PCBs). It is subject to strict government regulation as a toxic substance. A knowledge of government regulations is required because any liquid-filled transformer might contain some level of PCB's. (One reference is Toxic Substances Control Act as defined in the U.S. Code of Federal Regulations, 40CFR, Part 761. Copies may be obtained from the Industry Office of Toxic Substances, Environmental Protection Agency, Washington, D.C. 20460, Call 202-554-1404).

7-2.1.4 There are several types of transformer construction regarding the preservation of the liquid. Preservation means minimizing exposure of the insulating liquid to the atmosphere. The types are:

(a) Free breathing (open to the atmosphere).

(b) Restricted breathing (open to the atmosphere through dehydrating compounds).

(c) Conservator or expansion tank (exposure to air limited to the liquid in the conservator tank).

(d) Sealed tanks (a gas space above the liquid serves as a cushion for internal pressure).

(e) Gas-oil seal (exposure to air limited to the oil in the auxiliary tank).

(f) Inert gas (gas space above liquid maintained under positive pressure by gas supplied from a nitrogen cylinder).

7-2.1.5 Some common cooling methods are:

(a) Self-cooled (OA or OISC) — heat is dissipated by the tank surface and cooling fins or tubes.

(b) Forced-air-cooled (FA) — fans are employed to force air over the cooling surfaces to augment the self-cooled rating.

(c) Forced-air-cooled/forced-oil-cooled (FA/FOA) — an oil pump circulates oil through a fan blown oil-to-air-heat exchanger.

(d) Water-cooled (FOW) — heat exchange by means of water pumped through a pipe coil installed inside or outside the transformer tank.

7-2.2 Regular Inspections.

7-2.2.1 Inspections of transformers should be made on a regular basis. The frequency of inspection should be based on the importance of the transformer, the operating environment, and the severity of the loading conditions. Typical regular inspection data may include load current, voltage, liquid level, liquid temperature, winding hot-spot temperature, ambient temperature, leaks, and general condition.

7-2.2.2 The current, voltage, and temperature readings should be taken at the time of peak load and the liquid level reading at the end of a low load period. Permanent records should be kept of the readings. Keeping such records helps assure that the readings will be made and provides a means of ready comparison with previous conditions. Further explanations are covered in the following sections.

7-2.3 Current and Voltage Readings.

7-2.3.1 Load currents are a very important part of the recommended regular inspections. If the observed current in any phase exceeds the rated full load value, and the rated maximum temperature is exceeded, steps should be taken to reduce the load.

7-2.3.2 Overvoltages and undervoltages can be detrimental to the transformer and the load it serves. The cause should be investigated immediately and corrective action taken to bring the voltage within acceptable limits.

7-2.4 Temperature Readings.

7-2.4.1 Transformers are rated to carry their nameplate load in kVA with a given heat rise when the ambient temperature is at a standard level. Exact values are stated on the nameplate. For instance, a liquid-filled transformer may be rated to deliver nameplate capacity with a 65°C (149°F) temperature rise above a 30°C (86°F) ambient temperature (24-hour average).

7-2.4.2 If transformers have temperature gauges, readings should be regularly taken and recorded. If the gauge is also equipped with a maximum temperature indicator, readings from both indicators should be recorded and the maximum temperature indicator should be reset. Excessive temperature indicates an overload, or perhaps some interference with the normal means of cooling. Prolonged operation at overtemperature will accelerate the deterioration of the liquid and result in reduced life expectancy of the solid insulation. Either will greatly increase the risk of failure. In some installations, constant monitoring against overtemperature is provided by special alarm contacts on the temperature gauge.

7-2.5 Liquid-level Indicator and Pressure/Vacuum Gauges.

7-2.5.1 The liquid level should be checked regularly, especially after a long period of low load at low ambient temperature when the level should be at its lowest point. It is important that liquid be added before the level falls below the sight glass or bottom reading of the indicator. If a transformer is not equipped with a liquid-level indicator, the liquid level can be checked by removing the inspection plate on the top of the transformer or by removing the top if no inspection plate is available. The transformer must be de-energized prior to either of the above two procedures. See 7-2.7 for precautions relative to de-energizing the transformer and for the recommended procedures for adding liquid.

7-2.5.2 Pressure/vacuum gauges are commonly found on sealed-type transformers and are valuable indicators of the integrity of the sealed construction. Most sealed transformers have provisions for adding this device and, if feasible, it should be added. The readings should be compared to the recommendations of the manufacturer as to the normal operating ranges. High pressures indicate an overload or internal trouble and should be investigated immediately. A sustained zero pressure reading indicates a leak or a defective gauge.

7-2.6 Miscellaneous. The features of special types of transformer construction that should be included in regular inspections include:

(a) The water-in and water-out temperatures of water-cooled transformers.

(b) The oil-in and oil-out temperatures of forced-oil-cooled transformers with oil-to-air or oil-to-water heat exchangers.

(c) The pressure in the nitrogen cylinder for a transformer equipped with an automatic gas-pressure system — if the pressure drops below the manufacturer's recommended value (usually about 150 psi), the cylinder should be replaced, and leaks repaired.

(d) Dehydrating breathers should be checked to assure that they are free from restriction and have not absorbed excessive moisture.

7-2.7 Special Inspections and Repairs.

7-2.7.1 Because of the wide variety of liquid-filled transformer types, sizes, and uses, as previously listed, the special inspection and repair recommendations will be general in nature. For specific directions, the manufacturer's recommendations should be followed.

7-2.7.2 If a transformer is given an external visual examination, the case of the transformer should be regarded as energized until the tank ground connection is inspected and found to be adequate. If any procedure more extensive than an external visual examination is to be performed, the first precaution that should always be observed is to de-energize the transformer. De-energization should always be accompanied by approved positive lock-out or tag-out procedures to assure against an unplanned re-energization and resulting hazard to personnel or equipment. De-energization should be immediately followed by a test to assure that the equipment is de-energized. The equipment should be grounded prior to the start of any work. (*See Chapter 20.*)

7-2.7.3 All connections should be inspected for signs of overheating and corrosion. Insulators and the insulating surfaces of bushings should be inspected for tracking, cracks, or chipped skirts, and the gasketed bases for leaks. The insulating surfaces should be cleaned of any surface contamination. Damaged insulators or bushings should be replaced. Leaks should be repaired. Pressure-relief devices should be inspected to ensure that there are no leaks or corrosion and that the diaphragm or other pressure-relief device is intact and ready to function. A cracked or leaking diaphragm should be replaced at once.

7-2.7.4 The tank, cooling fins, tubes, radiators, tap changer, and all gasketed or other openings should be inspected for leaks, deposits of dirt, or corrosion. Leak repair, cleaning, and painting should be done as required.

7-2.7.5 The tank ground should be inspected for corrosion or loose connections. A grounding electrode resistance test should be made, as covered in Section 18-14.

7-2.7.6 Cooling fans, circulating oil pumps, and protective relays (e.g., Bucholtz relays, sudden-gas relays, etc.) should be inspected regularly in accordance with manufacturer's recommended practices.

7-2.7.7 The conservator tank, inert gas atmosphere, and dehydrating breather equipment should be inspected and tested according to the manufacturer's instructions. Since most modern, large, liquid-filled power transformers have features to minimize exposure of the liquid to air, opening of this type of transformer for internal inspection is recommended only when the need is positively indicated, and then the manufacturer's instructions should be carefully followed or technical assistance employed.

Contamination or impairment of the insulating liquid should be carefully avoided. If the humidity is high, exposure should be avoided entirely unless the work is absolutely necessary and cannot be postponed, in which case special humidity-control steps should be taken.

7-2.7.8 If liquid is to be added, it should be given a dielectric-breakdown test. The liquid to be added should be at least as warm as the liquid in the transformers. If a large amount of liquid is added, the transformer should remain de-energized for twelve hours or more to permit the escape of entrapped air bubbles. A desirable method is to add the liquid with the transformer tank under a vacuum. (Check the manufacturer's instructions and ANSI C57.93 for further information.)

7-2.8 Liquid Maintenance and Analysis.

7-2.8.1 Liquid Analysis.

(a) For insulating oils, the tests routinely performed are dielectric breakdown, acidity, color, power factor, interfacial tension, and visual examination. These tests are covered in Section 18-18. For other insulating liquids, the manufacturer's recommendations should be followed.

(b) Tests may also be performed to determine levels of PCBs. Test results may require service or replacement of the transformer tested as specified by government regulations. (*See 7-2.1.3.*)

(c) Samples should never be taken from energized transformers except by means of an external sampling valve. If the transformer has no external sampling valve, the unit must first be de-energized and a sample taken internally. (*See ASTM D923.*)

7-2.8.2 Maintenance. If any of the tests indicate that an insulating liquid is not in satisfactory condition, it may be restored by reconditioning, reclaiming, or it can be completely replaced. Reconditioning is the removal of moisture and solid materials by mechanical means such as filter presses, centrifuges, or vacuum dehydrators. Reclaiming is the removal of acidic and colloidal contaminants and products of oxidation by chemical and absorbent means such as processes involving Fuller's earth, either alone or in combination with other substances. (*See IEEE 64.*) Replacing the liquid involves draining, flushing, testing, and proper disposal of materials removed.

7-2.9 Other Tests.

7-2.9.1 In addition to the tests of the insulating liquid, tests should also be made of the dielectric properties of the solid insulation. Several commonly used tests are the insulation-resistance test and the dielectric-absorption test. A power factor test can be used to record the trend of insulation condition. These are nondestructive tests, which means that they may be performed without the risk of damage to the insulation. All of these tests are discussed in Chapter 18.

7-2.9.2 Turns Ratio and Polarity Tests.

(a) The turns ratio test is used to determine the number of turns in one winding of a transformer in relation to the number of turns in the other windings of the same phase of the transformer. The polarity test determines the vectoral relationships of the various transformer windings. The turns ratio test is used as both an acceptance and a maintenance test, while the polarity test is primarily an acceptance test.

(b) The test equipment used will ordinarily be a turns ratio test set designed for the purpose. If not available, input and output voltages can be measured, with at least 0.25 percent full-scale accuracy voltmeters, for approximation.

(c) When a turns ratio test is performed, the ratio should be determined for all no-load taps. If the transformer is equipped with a load-tap changer (LTC), the ratio should be determined for each LTC position. If the transformer has both an LTC and a no-load tap changer, then the ratio should be determined for each position of the LTC to one position of the no-load tap changer and vice versa.

This test is useful in determining whether a transformer has any shorted turns or improper connections and, in acceptance testing, to verify nameplate information.

7-2.9.3 Fault-Gas Analysis. (*See ASTM D3284.*) The determination of the percentage of combustible gases present in the nitrogen cap of sealed, pressurized oil-filled transformers can provide information as to the likelihood of incipient faults in the transformer. When arcing or excessive heating occurs below the top surface of the oil, insulation decomposition may occur. Some of the products of the decomposition are combustible gases that rise to the top of the oil and mix with the nitrogen above. A small sample of nitrogen is removed from the transformer and analyzed. The test set has a direct reading scale calibrated in percent of combustible gas. Ordinarily, the nitrogen cap in a transformer will have less than one-half percent combustible content. As a problem develops over a period of time, the combustible content can rise to ten or fifteen percent.

A suggested evaluation of the test results is as follows:

Percentage of Combustible Gas	Evaluation
0.0 to 1.0	No reason for concern. Make tests at regularly scheduled intervals.
1.0 to 2.0	Indication of contamination or slight incipient fault. Make more frequent readings and watch trends.
2.0 to 5.0	Begin more frequent readings immediately. Prepare to investigate cause by internal inspection.
over 5.0	Remove transformers from service and make internal inspection.

7-2.9.4 Dissolved-Gas-In-Oil Analysis. A refinement of the Fault-Gas Analysis is the Dissolved-Gas-In-Oil Test (*ASTM D3612*). In this test, an oil sample is withdrawn from the transformer and the dissolved gases are extracted from the oil. A portion of the gases are then subjected to chromatographic analysis. This analysis determines the exact gases present and the amount of each. Different types of incipient faults have different patterns of gas evolution. With this test, the nature of the problems can often be diagnosed. (*See ANSI/IEEE C57.104-1978.*)

7-3 Dry-type Transformers.

7-3.1 General.

7-3.1.1 Dry-type transformers operate in air or gas rather than being liquid filled. The two general types of construction are the open or ventilated dry-type transformer and the sealed or closed tank type. Dry transformers are usually varnish impregnated or cast coil construction. Sealed transformers are cooled and insulated by a high-dielectric inert gas, such as nitrogen, sulphur hexafluoride, or perfluoropropane.

7-3.1.2 The air or gas serves as an insulating medium and also to dissipate heat from the windings. Standard insulation classes are 80°C rise, 115°C rise, and 150°C rise.

7-3.2 Regular Inspections. The comments in 7-2.2 regarding regular inspections of liquid-filled transformers also apply to dry-type transformers, with the exception of those that obviously pertain strictly to liquid-filled construction.

7-3.3 Current and Voltage Readings. The comments in 7-2.3 regarding current and voltage readings also apply to dry-type transformers.

7-3.4 Temperature Readings. The comments in 7-2.4 regarding temperature readings also apply to dry-type transformers. However, dry-type transformers usually have high-temperature insulation and might operate at higher temperatures than liquid-filled units.

7-3.5 Pressure/Vacuum Gauge.

7-3.5.1 Sealed dry-type transformers are usually equipped with pressure/vacuum gauges. The gauge should be read periodically and the readings recorded. The readings should be compared to the manufacturer's recommended normal operating range. Lower-than-normal or zero readings are an indication of a leak in the tank. If the leak is not severe, it may be desirable to periodically replace the gas or recharge the transformer instead of locating and sealing the leak. The replacement gas must be either the same as the original or an approved substitute. (*See 7-3.7 for the recommendations covering severe leaks.*)

7-3.5.2 High pressures are an indication of electrical overload or internal trouble. They should be immediately investigated and corrective action taken. Excessive pressure can result in distortion or rupture of the tank.

7-3.6 Miscellaneous. The louvers in the enclosures of ventilated dry-type transformers should be inspected to see that they are not clogged with dirt or otherwise obstructed. Also, the operation of integral ventilating fans should be checked. Dry-type transformers are usually installed indoors and sometimes in a vault. The temperature of the vault or room should be measured regularly and recorded. Proper ventilation is essential to the operation of a transformer. Any material or obstruction that might prevent the free circulation of air around a transformer should be removed. If the room or vault has power-driven ventilating fans, their correct operation (air velocity should not exceed 400 feet per minute) should be determined and overtemperature alarms, if provided, should be tested. Corrosion of the transformer enclosure, the intrusion of dirt, as well as evidence of water leaks into the room or vault, should also be carefully checked and corrective measures taken as required. A high noise level or change in level could indicate improper installation or loose windings or barriers.

7-3.7 Special Inspections and Repairs.

7-3.7.1 When a transformer is given an external visual exmination, the transformer case should be regarded as energized until the case-ground connection is inspected and found to be adequate. If any procedure more extensive than an external visual examination is to be performed, the first precaution that should always be observed is to de-energize the transformer. De-energization should be accompanied by approved positive lock-out procedures to assure against an unplanned re-energization and resulting hazard to personnel or equipment. De-energization should be immediately followed by a test to assure that the equipment is de-energized. The equipment should be grounded prior to the start of any work. (*See Chapter 20.*)

7-3.7.2 Enclosure covers of ventilated dry-type transformers should be removed carefully. An inspection for the following problems should be made:

(a) Accumulations of dirt on windings, insulators, and where cooling airflow might be restricted.

(b) Discoloration caused by overheating.

(c) Tracking and carbonization.

(d) Cracked or chipped insulators.

(e) Loose insulators, clamps, or coil spacers.

(f) Deterioration of barriers.

(g) Corroded or loose electrical connections.

In addition, the equipment ground should be inspected for corrosion or loose connections. A grounding-electrode resistance test should be made as covered in Section 18-14.

7-3.7.3 Dirt and dust should be cleaned from the windings with a vacuum cleaner. After vacuum cleaning, compressed air may be used, only if it is clean and dry and applied at a low pressure to avoid damage to windings. In particular, ventilating ducts and the top and bottom of the windings should be cleaned. The use of liquid cleaners should be employed only when it is known that they will not have a deteriorating effect on the insulation.

7-3.7.4 Best service life will result if the windings are maintained above the ambient temperature level. For this reason, transformers operating in high humidity should be kept energized, if feasible. If a transformer is to be de-energized long enough for it to cool, special drying procedures may be required before the transformer is re-energized. Refer to the manufacturer's recommendations for drying procedures to be followed.

7-3.7.5 Sealing severe leaks or opening and resealing the tanks of sealed dry-type transformers requires special procedures and equipment. The manufacturer of the transformer, an experienced transformer repair facility, or a qualified electrical maintenance contractor should perform this work.

In addition, special procedures covering drying out of the windings, plus purging and refilling of the tank, may be required.

7-3.8 Insulation Tests. The insulation tests covered in 7-2.9.1 and 7-2.9.2 may also be applied to dry-type transformers.

Chapter 8 Power Cables

8-1 General. Preventive maintenance is the best way to assure continued reliable service from electrical cable installations. Visual inspection and electrical testing of the insulation are the major maintenance procedures. However, it must be stressed that no amount of maintenance can correct improper application or physical damage done during installation.

8-2 Visual Inspection.

8-2.1 If, in addition to the visual inspection, cables are to be touched or moved, they should be de-energized.

8-2.2 Cables in manholes should be inspected for sharp bends, physical damage, excessive tension, oil leaks, pits, cable movement, insulation swelling, soft spots, cracked jackets in nonlead cables, damaged fireproofing, poor ground connections, deterioration of metallic sheath bonding as well as corroded and weakened cable supports, and the continuity of any main grounding system. Terminations and splices of nonlead cables should be squeezed in search of soft spots and inspected for tracking of signs of corona. The ground braid should be inspected for corrosion and tight connections. Inspect the bottom surface of the cable for wear or scraping, due to movement, at the point of entrance into the manhole and also where it rests on the cable supports.

8-2.3 Inspect the manhole itself for spalling concrete or deterioration of the aboveground portion. In some instances, the manhole may be equipped with drains, and these may require cleaning; in some instances, it may be necessary to pump water from the manhole prior to entrance. Do not enter a manhole unless a test for dangerous gas has been made and adequate ventilation is provided. The inspection crew should always consist of two or more persons with at least one remaining outside of the manhole.

8-2.4 Potheads should be inspected for oil or compound leaks and cracked or chipped porcelains. The porcelain surfaces should be cleaned and, if the connections are exposed, their tightness should be checked.

8-2.5 Cable identification tags or marking should be checked.

8-2.6 Since inspection intervals are normally one year or more, comprehensive records are an important part of any maintenance program. They should be arranged to facilitate comparison from year to year.

8-3 Aerial Installations. Aerial cable installations should be inspected for mechanical damage due to vibration, deteriorating supports, or suspension systems. Special attention should be given to the dead-end supports to assure that the cable insulation is not abraded, pinched, or bent too sharply. Terminations should be inspected as covered in 8-2.2.

8-4 Raceway Installations. Since the raceway is the primary mechanical support for the cable, it should be inspected for signs of deterioration or mechanical damage or if the cable jacket is being abraded or mechanically damaged. In many installations, the raceway serves as a part of the ground-fault current circuit. Joints should be inspected for signs of looseness or corrosion that could result in a high resistance. The other recommendations for splices and terminations covered in 8-2.2 should also apply in this section.

8-5 Testing. (*See Chapter 18.*) The two most commonly used tests for cable insulation are insulation resistance testing and dc over-potential testing. Other tests are listed in IEEE 62, *Making Dielectric Measurements in the Field.* The cable must be de-energized prior to the application of any test.

Chapter 9 Motor Control Centers

9-1 General. There are many varieties of motor control centers and molded-case circuit breaker power panels. These maintenance recommendations are general in nature and can be adapted to a wide variety of product types.

9-2 Enclosures. Enclosures do not normally require any maintenance in a clean, dry, and noncorrosive atmosphere. Enclosures in a marginal atmosphere should be inspected periodically for excessive dust and dirt accumulation as well as corrosive conditions. The more contaminated the atmosphere, the more frequently the inspections should be conducted. Any accumulation should be removed with a vacuum cleaner or manually cleaned during maintenance shutdown periods for the equipment. Badly corroded enclosures should be properly cleaned and refinished as required for extended service.

9-3 Busbar and Terminal Connections.

9-3.1 Warning. Any loose busbar or terminal connection will cause overheating that will lead to equipment malfunction or failure. Overheating in a bus or terminal connection will cause a discoloration in the busbar which can easily be spotted where connections are visible — oftentimes too late to avoid replacement. An overheating busbar condition will feed on itself and eventually lead to deterioration of the bus system as well as the equipment connected to the bus such as: protective devices, bus stabs, insulated leads, etc. Aluminum lug connectors are usually plated and should not be cleaned with abrasives.

9-3.2 Loose Connections. Busbar and terminal connections should be inspected periodically to ensure that all joints are properly tightened. Proper torque tightness is a factor of bolt size, bolt type, and type of busbar and terminal material. Proper bolt tightness torque values for all types of joints involved should be available in manufacturer's maintenance and instructional literature. *Do not assume that busbar and terminal hardware, once tightened to proper torque values, remains tight indefinitely.*

9-3.3 Special Operating Environments. Special attention should be given to busbars and terminal connections in equipment rooms where excessive vibration or heating/cooling cycles may cause more than normal loosening of bolted bus and terminal connections.

9-3.4 Busbar Support Insulators. Busbar support insulators and barriers should be inspected to ensure that they are free of contamination. Insulators should be periodically checked for cracks and signs of arc tracking. Defective units should be replaced. Loose mounting hardware should be tightened.

9-4 Disconnects.

9-4.1 Warning. Disconnects should be examined on both the line and load side for proper maintenance evaluation. Prior to initiating such an evaluation, the source side disconnect device should be opened and padlocked and tagged to avoid accidental energization by other personnel during maintenance operations. Switches used in drawout units normally supplied in motor control centers can be opened and safely withdrawn and examined on a workbench, thus avoiding this potential hazard.

9-4.2 Safety. Never assume that a disconnect is in the open position because the handle mechanism is in the open position. Always double-check for safety.

9-4.3 Inspection and Cleaning. Disconnect switches generally have visible blade contacts and open-type mechanisms that can be susceptible to contamination when not enclosed in a proper enclosure. Therefore, routine maintenance should include a procedure for inspecting and removing excessive dust accumulations. Nonautomatic molded-case circuit interrupters are often used in motor control circuits in lieu of an open-type disconnect. For this type of application, the internal mechanism will be better protected against contamination. The exterior should be examined and cleaned as outlined in Section 11-7.

9-4.4 Loose Connections. Excessive heat in a disconnect switch can lead to deterioration of the insulation and eventual failure of the device. Loose connections are the major source of excessive heat. Terminal and busbar connections as well as cable connections should be examined and tightened as required using the manufacturer's torque recommendations. Any device having evidence of overheated conductors and carbonized insulation that could also be caused by arcing should be replaced. Contacts should be examined for evidence of welding or excessive pitting. Damaged disconnects with any evidence of these failure signs should be replaced.

9-4.5 Mechanical Operation. Mechanisms should be manually operated to ensure proper working condition. Factory lubricated mechanisms will sometimes dry out after a period of time in dry, heated atmospheres as in motor control center enclosures. Manufacturers' maintenance literature should be followed for proper lubrication instructions.

9-5 Fuses — Warning. Fuses are normally used in conjunction with disconnect switches. In no case should a dummy fuse, copper slug, or length of wire ever be used as a proper fuse substitute, even on a temporary basis. Proper fuse and fuseholder maintenance is covered in Chapter 13.

9-6 Contactors.

9-6.1 General. Since contactors are the working portion of a motor controller, normal wear can be expected.

9-6.2 Inspection and Replacement. Periodic inspections should be made to ensure that all moving parts are functioning properly. Badly worn or pitted contacts should be replaced in sets to avoid possible misalignment. Dressing contacts should not be performed simply as a cleaning operation; rather, it should be done only to the degree necessary to restore proper contour. Silver alloy or noble metal contacts should be dressed with a crocus cloth or other suitable nonconductive abrasive. Materials such as emory cloth and steel wool should not be used. Routine inspection should always include checks for tightness of terminal and cable connections as well as for signs of overheating. Replacements should be made as conditions dictate. Contactors installed in corrosive or lint-filled atmospheres require more frequent inspection, even when enclosed in special gasketed enclosures. Many manufacturers of starters, contactors, and relays using silver alloy contacts specifically warn users against filing silver alloy contacts. Manufacturers' recommendations should be followed closely for maintenance and replacement of parts.

9-7 Motor Overload Relays — Thermal Types.

9-7.1 General. Motor overload relays perform the vital supervisory function of monitoring the overload current conditions of the associated motor. Heater elements are usually replaceable; however, if a trip or burnout of the element occurs, the cause of this trip or burnout should be identified and corrected. Replacement of the heater element with one of a higher rating should not be done without full consideration of the ambient temperature in which the motor operates, as well as all of the factors in 9-7.3. Such overload relays employ a thermal element designed to interpret the overheating condition in the motor windings by converting the current in the motor leads to heat in the overload relay element. As the heat in the thermal element reaches a predetermined amount, the control circuit to the magnetic contactor holding coil is interrupted and the motor branch circuit is opened. The two most common types of thermal elements in overload relays employ either a bimetal or a melting alloy joint to initiate the opening action of the contactor.

9-7.2 Other Types. Refer to manufacturer's literature for maintenance of other types of overload devices.

9-7.3 Motor Data. Overload thermal elements are applied on the basis of motor full-load current and locked rotor data found on the motor rating nameplate. Complete records on all motors including motor full-load amps together with proper manufacturer's heater selection and application charts should be included as a part of any maintenance file on motor starters. General heater application charts for the size of contactor involved are usually secured inside the starter enclosure.

9-7.4 Inspection and Replacement. Routine maintenance should include a check for loose terminal or heater connections and signs of overheating. Overheating can cause carbonization of the molding material creating potential dielectric breakdowns as well as possibly altering the calibration of the overload relay. Relays showing signs of excessive heating should be replaced.

9-8 Pilot and Miscellaneous Control Devices.

9-8.1 General. Pilot and other control devices consist of the control accessories normally employed in motor starters and include: pushbuttons, selector switches, indicating lights, timers, auxiliary relays, etc.

9-8.2 Inspection. Routine maintenance checks on these types of devices generally include the following:

(a) Check for loose wiring.

(b) Check for proper mechanical operation of pushbuttons and contact blocks.

(c) Inspection of contacts (when exposed).

(d) Check for signs of overheating.

(e) Replacement of pilot lamps.

9-9 Interlocks.

9-9.1 Electrical Interlocks. A contactor or starter may be provided with auxiliary contacts that permit interlocking with other devices as well as serve other position indicating functions.

9-9.2 Inspection. Proper maintenance of these electrical auxiliary contacts includes the following:

(a) Check for loose wiring.

(b) Check for proper mechanical operation and alignment with the contactor.

(c) Inspection of contacts (when exposed).

9-9.3 Mechanical Interlocks. Mechanical interlocks can be classified in two categories according to their application: safety and functional performance. Safety interlocks are designed to protect operating personnel by preventing accidental contact with energized conductors and the hazards of electrical shock. Functional interlocks, such as those found on reversing contactors, are designed to prevent the inadvertent closing of parallel contactors wired to provide alternate motor operating conditions. Motor control centers are provided with plug-in starters for ease of inspection and interchangeability. Mechanical interlocks should be examined to ensure that the interlock is free to operate and that bearing surfaces are free to perform their intended function. Interlocks showing signs of excessive wear and deformation should be replaced. Several types of locking or interlocking features are used including the following.

9-9.4 Primary Disconnect Mechanism. This device is usually mounted directly on the disconnect device in the plug-in unit. It is mechanically interlocked with the door to ensure that the door is held closed with the primary disconnect in the "ON" position. A maintenance check should be made to ensure that the adjustment is correct and that the interlock is providing proper safety.

9-9.5 Padlock Mechanism. Disconnect operating mechanisms are usually provided with padlocking means whereby the mechanism can be padlocked "OFF" with multiple padlocks while the door is closed or after it is opened. During maintenance checks in the unit, as well as downstream at the motor, these mechanisms should be padlocked in the "OFF" position for personnel safety.

9-9.6 Defeat Mechanisms. Most starters are equipped with defeater mechanisms that can be operated to release door interlock mechanisms with the disconnect device in the "ON" position. The use of this release mechanism should be limited to qualified maintenance and operating personnel.

9-9.7 Unit Lock. Plug-in motor-starter units are normally held locked in their connected cell positions by a unit latch assembly. Maintenance on this assembly is not normally required but should be understood by maintenance personnel.

Chapter 10 Electronic Equipment

10-1 General. The purpose of this section is to describe the maintenance of electronic equipment in general terms. Specific maintenance procedures normally are available from the equipment manufacturer or contained in the instruction book supplied with the apparatus. In some cases these procedures require the services of trained specialists.

10-2 Reasons for Maintenance.

10-2.1 Maintenance procedures are designed to:

(a) Protect the equipment from adverse effects of heat, dust, moisture, and other contaminants.

(b) Maintain top reliability and minimize costly downtime.

(c) Prolong the useful life of the equipment.

(d) Recognize incipient problems and take corrective action.

10-2.2 The importance of maintenance cannot be overemphasized. Equipment must be kept operating efficiently to contribute to the success of the process or operation in which the equipment is employed. Apparatus that is improperly maintained will soon become unreliable.

10-2.3 Persons charged with maintenance responsibility should have a keen appreciation as to why the work is required and the importance of even routine aspects of maintenance to the overall performance of the equipment.

10-3 Special Safety Precautions.

10-3.1 Special safety precautions should be observed before and during the preventive maintenance operation. Extreme care should be taken to assure that all power is removed from the apparatus before servicing. To prevent accidental shock from the stored energy in capacitors, discharge them to ground or short circuit the leads before touching with bare hands. High-voltage capacitors should be discharged by short circuiting the leads for at least one full minute. Parts such as tubes, resistors, heat sinks, etc., remain extremely hot for some time after power has been removed. Some component temperatures are very high and can cause very painful burns if contacted by bare skin.

10-3.2 An accidental shock or a bad burn may cause an involuntary movement by a person's arm or body that can damage the equipment and injure personnel.

10-3.3 Occasionally, some equipment employing high voltages requires troubleshooting while the circuits are energized. Ensure that the insulation on test equipment leads is fully rated for the operating voltage under test and in good mechanical condition. Special care should be observed when using or servicing equipment that employs the chassis as one side of the circuit. Such equipment may be hazardous in the presence of grounded or some ungrounded three-phase circuits.

10-4 Preventive Maintenance Operations. Actual work performed during maintenance consists of the following operations:

(a) Cleaning.

(b) Inspection.

(c) Adjustments.

(d) Lubrication.

10-4.1 Cleaning. Cleaning the apparatus, both inside and out, is essential for good operation. Dust, etc., will increase chances of current leakage or flashover with resultant malfunction or damage to critical parts. Any accumulation of dust should be removed with a vacuum cleaner, if possible, or manually cleaned during maintenance shutdown periods. Enclosure filters should be cleaned at regular intervals and replaced when damaged or clogged.

10-4.2 Inspection. Inspection is most important in the maintenance program. Slight abnormalities may not immediately interfere with the equipment performances, but deviations from normal should be discovered early. Time and effort can be saved if defects are corrected before they lead to major breakdowns. Inspections consist of carefully observing all parts of equipment, noticing their color, placement, state of cleanliness, etc. Inspect for conditions such as:

(a) *Overheating* — indicated by discoloration or other visual characteristics.

(b) *Placement* — by observing leads and cable clearances, rub points, etc.

(c) *Cleanliness* — examine recesses for accumulation of dust, especially between connecting terminals. Parts, connections, and joints should be free of dust, corrosion, and other foreign material.

(d) *Tightness* — test soldered or screw terminal connections and mountings by slightly pulling on the wire or feeling the lug or terminal screw.

10-4.3 Adjustments. Adjustments should be made only when performance indicates that it is required in order to maintain normal operating conditions. Specific adjustments vary with each type of equipment and will be contained in the instruction booklets supplied with the apparatus. Equipment calibrations should be scheduled on a routine basis with the frequency depending on individual operating conditions peculiar to the process or equipment.

10-4.4 Lubrication. Lubrication refers to application of grease or oil to bearings of motors, rotating shafts, gears, etc. This can also include light lubrication to door hinges or other sliding surfaces on the equipment. Some special parts are identified as being prelubricated for life and should require no further lubrication.

10-4.5 Careful handling of electronic equipment should become a regular habit. Space for working on components partially covered by other components should not be made by pushing or moving other components out of the way. Avoid unnecessary strains on wires, cables, and connections, and maintain equipment in a neat, orderly, workmanlike manner.

Chapter 11 Molded-Case Circuit-Breaker Power Panels

11-1 General. Molded-case circuit breakers undergo extensive production testing and calibration at the manufacturers' plants. These tests are based on Underwriters Laboratories Inc., No. 489, *Safety Standard for Branch Circuit and Service Circuit Breakers*. Circuit breakers carrying the UL label have factory-sealed, calibrated elements; an unbroken seal assures that the mechanism has not been subjected to alteration or tampering, and that the breaker may be expected to perform according to the UL specifications. A broken seal voids the UL label and jeopardizes the manufacturer's warranty.

11-2 Application Considerations. Molded-case circuit breakers will trip from exposure to continuous currents beyond their ratings, and many trip from unduly high ambient temperatures, from poor or improper connections, from damaged plug-in members, and from other conditions that transfer undue heat to the breaker mechanism. Some of these conditions violate application specifications. A molded-case circuit breaker applied in a panelboard should not be loaded in excess of 80 percent of its continuous current rating, where in normal operation the load will continue for three hours or more.

11-3 Phase Fault Current Conditions. A typical molded-case circuit breaker is equipped with both time-delay and instantaneous tripping devices. Time-delay tripping has inverse time characteristics that provide a shorter tripping time for higher overloads. Under moderate, short-duration overloads, the circuit breaker allows sufficient time for such applications as motor starting. Under severe overloads, the circuit breaker will trip quickly, providing adequate protection for conductors and insulation. For high-fault currents, the magnetic tripping device responds to open the circuit breaker immediately.

11-4 Ground-Fault Tripping. It should be recognized that standard molded-case circuit breakers are not generally equipped with ground-fault sensing and protection devices and, therefore, will not normally trip and clear low-level ground faults that can do immense damage. Special ground-fault sensing and protective devices should be specified to achieve this type of equipment protection where required. (*See Section 12-3.*)

11-5 Types of Molded-Case Circuit Breakers. Molded-case circuit breakers can generally be divided into three major categories depending on the type of trip unit employed:

(a) Factory sealed, noninterchangeable trip.

(b) Interchangeable trip.

(c) Solid state.

The most common type of trip unit under (a) and (b) is the standard time-limit or thermal-magnetic trip. This type of trip unit employs a thermal element to provide inverse characteristics giving overload protection and a magnetic circuit to provide short-circuit protection. Another common type of trip under type (a) is the hydraulic-magnetic trip where a dashpot is used to achieve the inverse time delay. These functions are accomplished with the use of solid-state circuitry in type (c), as well as other functions including ground-fault protection not normally available as an integral part of breakers under types (a) and (b).

11-6 Special-Purpose Breakers. A special design of an Instantaneous Only circuit breaker having an adjustable instantaneous pickup is utilized in motor-circuit protection schemes.

11-7 Types of Maintenance. Maintenance of molded-case circuit breakers can generally be divided into two categories: mechanical and electrical. Mechanical maintenance consists of inspection involving good housekeeping, maintenance of proper mechanical mounting and electrical connections, and manual operation as outlined in the following paragraphs. Electrical testing under field test conditions is covered in 18-10.2.4.

11-8 Inspection and Cleaning. Molded-case circuit breakers should be kept clean of external contamination so that internal heat can be dissipated normally. Further, a clean case will reduce potential arcing conditions between live conductors and between live conductors and ground. The structural strength of the case is important in withstanding the stresses imposed during fault-current interruptions. Therefore, an inspection should be made for cracks in the case and replacements made where required.

11-9 Loose Connections. Excessive heat in a circuit breaker can cause a malfunction in the form of nuisance tripping and possibly an eventual failure. The most common cause of excessive heat is loose connections. Periodic maintenance checks should involve checking for loose connections or evidence of overheating. Loose connections should be tightened as required using manufacturers' recommended torque values. Molded-case circuit breakers having noninterchangeable trip units are properly adjusted, tightened, and sealed at the factory. Those having interchangeable trip units installed away from the factory could overheat if not tightened properly during installation. All connections should be maintained in accordance with manufacturers' recommendations.

11-10 Components of a Circuit Breaker. A molded-case circuit breaker consists of two basic parts. One part consists of the current-carrying conductors, contacts, and appropriate operating mechanism necessary to perform the circuit-switching functions. The second part consists of the protective element including the tripping mechanism associated therewith.

11-11 Mechanical Mechanism Exercise. There is adequate experience to indicate that where electrical testing is not practical, or cannot be justified, the manual mechanical exercising of the circuit breaker is usually effective in assuring the probable electrical operation. All devices with moving parts require periodic check-ups. A molded-case circuit breaker is no exception. It is not unusual for a molded-case circuit breaker to be in service for extended periods and never be called upon to perform its overload- or short-circuit-tripping functions. Therefore, a few manual operations of the handle performed periodically will keep the mechanism free while wiping action by the contacts tends to avoid resistance build-up and also minimizes heating. Circuit breakers used for frequent switching need no further exercising. Although manual operations will exercise the breaker mechanism, none of the mechanical linkages in the tripping mechanisms will be moved with this manual exercise. Some circuit breakers have push-to-trip buttons that should be operated at the time of manual exercising in order to move the tripping mechanism linkages.

Chapter 12 Ground-Fault Protection

12-1 General.

12-1.1 Ground-fault protective devices intended to protect personnel or systems from ground faults are of two distinct types and IT IS EXTREMELY IMPORTANT TO UNDERSTAND THE DIFFERENCE BETWEEN THEM.

(a) *GFCI — Ground-Fault Circuit-Interrupter.* A GFCI is designed to protect a person from electrocution when contact between a live part of the protected circuit and ground causes current to flow through a person's body.

A GFCI will disconnect the circuit when a current equal to or higher than the calibration point (4 to 6 mA) flows from the protected circuit to ground. It will not eliminate the shock sensation since normal perception level is approximately 0.5 mA. It will not protect from electrocution on line-to-line contact since the nature of line-to-line loads cannot be distinguished.

(b) *GFP — Ground-Fault Protector.* A GFP is designed to limit damage to electrical equipment in the event of a fault (either solid or arcing) between a live part of the protected circuit and ground. A GFP will cause the circuit to be disconnected when a current equal to or higher than its setting flows to ground. GFPs are available with settings typically ranging from 5 to 1200 amperes. It will not protect personnel from electrocution.

12-2 Ground-Fault Circuit-Interrupters (GFCI).

12-2.1 GFCIs are equipped with an integral test means for checking the tripping operation.

12-2.2 Maintenance.

12-2.2.1 The devices are sealed at the factory, and maintenance should be limited to that recommended as follows or by the manufacturer.

12-2.2.2 Separate test apparatus is available that may be used for acceptance testing and troubleshooting of GFCIs.

12-2.2.3 In addition to the maintenance specified for the individual types of GFCIs, tripping tests should be performed with the test button on the unit in accordance with the frequency recommended by the manufacturer. Results and dates of tests should be recorded on the test record label or card supplied with each permanently installed GFCI unit.

12-2.3 The four types of GFCIs are:

(a) Circuit breaker type.

(b) Receptacle type.

(c) Portable type.

(d) Permanently mounted type.

12-2.4 A circuit-breaker-type GFCI is designed in the form of a small circuit breaker and is completely self-contained within the unit housing. The circuit-breaker-type GFCI provides overload and short-circuit protection for the circuit conductors in addition to ground-fault protection for personnel. It is intended to be mounted in a panelboard or other enclosure.

12-2.4.1 Maintenance required is the same as specified in Chapter 11 for Molded-Case Circuit Breakers.

12-2.5 A receptacle-type GFCI is designed in the form of a standard receptacle and is completely self-contained within the unit housing and does not provide overload or short-circuit protection. It is intended for permanent installation in conventional device outlet boxes or other suitable enclosures.

12-2.5.1 Maintenance required will be the same as specified in Section 16-3 for standard receptacle outlets.

12-2.6 A portable-type GFCI is a unit intended to be easily transported and plugged into a receptacle outlet. Cords, tools, or other devices to be provided with ground-fault protection for personnel are then plugged into receptacles mounted in the unit.

12-2.6.1 Maintenance required will be that specified in Section 16-3 for receptacles and in Section 17-4 for the connecting cords.

12-2.7 A permanently mounted-type GFCI is a self-contained, enclosed unit designed to be wall or pole mounted and permanently wired into the circuit to be protected.

12-2.7.1 Maintenance beyond tightness of connections and cleanliness should not be attempted. Any repairs needed should be referred to the manufacturer.

12-3 Ground-Fault Protectors (GFP).

12-3.1 A GFP system is designed to be installed in a grounded distribution system. A GFP system consists of three main components: (1) sensors, (2) relay or control unit, and (3) a tripping means for the disconnect device controlling the protected circuit. Acceptance testing of the complete system is recommended before utilization of the equipment.

12-3.2 Detection of ground-fault current is done by either of two basic methods. With one method, ground current flow is detected by sensing current in the grounding conductor. With the other method, all conductor currents are monitored by either a single large sensor or several smaller ones.

12-3.3 Sensors are generally a type of current transformer and are installed on the circuit conductors. The relay or control unit may be remotely mounted from the sensors or may be integral with the sensor assembly.

12-3.4 Circuit breakers with electronic trip units may have a GFP system integral with the circuit breaker. Any maintenance work performed on the electronic circuitry should adhere to manufacturer's instructions. Maintenance on the mechanical operating mechanism components should be done as indicated in Chapter 11.

12-3.5 Maintenance.

12-3.5.1 Maintenance requirements for the sensors are as specified in Chapter 6, Section 6-8.5.2 for indoor-type instrument transformers. Make careful inspection for tight terminal connections and cleanliness. Any repairs needed should be performed by the manufacturer.

12-3.5.2 If interconnections between components are disconnected, they must be marked and replaced to maintain the proper phasing and circuitry.

12-3.5.3 If the system is equipped with a test panel, a formal program of periodic testing should be established. When the system is not equipped with a test panel, refer to manufacturer for test instructions.

Chapter 13 Fuses

13-1 Low-Voltage Fuses.

13-1.1 Installing and Removing Fuses. Whenever possible, de-energize fuseholders before installing or removing fuses.

13-1.2 Inspection and Cleaning. Be sure that the fuse is disconnected from all power sources before servicing. Examine fuse terminals and fuseholder clips for discoloration caused by heat from poor contact or corrosion. Tighten all fuseholder connections. Fuse clips should exert sufficient pressure to maintain good contact, which is essential for proper fuse performance. Clips that make poor contact should be replaced. Clip clamps are recommended when unsatisfactory clips cannot be replaced. Contact surfaces of clips and fuse terminals that are oxidized or corroded should be cleaned and polished. Silver-plated surfaces should not be abraded. Wiping contact surfaces with a noncorrosive cleaning agent is recommended. Replace fuses showing signs of deterioration such as discolored or damaged casings and loose terminals caused by heat from poor contact. Causes of overheating should be determined and corrected.

13-1.3 Replacement. There are many types of fuses with various characteristics, some of which are physically interchangeable. Make certain that fuses, whether new or replacements, are of the proper type and rating. Never replace one type of fuse arbitrarily with another type fuse of the same physical size simply because it fits the fuseholder. Fuses should have correct current and voltage ratings, proper time-delay and current-limiting characteristics, and an adequate interrupting rating to protect the circuit and its components. UL presently lists fuses for ac applications only. Fuses for dc applications are available in different types and ratings. Contact fuse manufacturers for application data. Voltage ratings of fuses must equal or exceed their circuit voltage. Time-delay fuses are advantageous for motor and transformer circuits having inrush current requirements. They allow these circuits to be fused at or near full-load current. All fuses should have interrupting ratings at least equal to the available fault current at the fuseholder as required by NFPA 70, *National Electrical Code*, Section 110-9. UL listed fuses without marked interrupting ratings are satisfactory on circuits where fault currents do not exceed 10,000 amperes. UL listed fuses are marked with their interrupting rating if it is above 10,000 amperes. Non-current-limiting fuses should not replace current-limiting fuses. Fuses which are listed by UL as current-limiting fuses are marked "Current Limiting." The dimensions of these fuses, in ratings up to and including 600 amperes, are different than non-current-limiting fuses. UL listed Class L fuses having ratings of 601 through 6000 amperes are marked "Current Limiting." Fuseholders for UL listed current-limiting fuses are designed to reject fuses that are not current limiting. Fuseholders and rejection clips should never be altered or forced to accept fuses that do not readily fit. An adequate supply of fuses with proper ratings, especially those that are uncommon, will minimize improper replacement. (*See 6-8.3.4 for capacitor fusing.*)

13-2 High-Voltage Power Fuses.

13-2.1 General. High-voltage power fuses consist of many parts, some current carrying and some non-current carrying, all subject to atmospheric conditions. These fuses may be current limiting or non-current limiting, sand or liquid filled, or vented expulsion type. The frequency of inspection will necessarily be a function of the conditions at a given fuse location and must be determined by the user.

13-2.2 Installing and Removing Fuses. Whenever possible, de-energize fuseholders before installing or removing fuses.

13-2.3 Inspection and Cleaning.

13-2.3.1 Be sure that the fuse is disconnected from all power sources before servicing. Inspect insulators for breaks, cracks or burns. Clean the insulators, particularly where abnormal conditions such as salt deposits, cement dust or acid fumes prevail, to avoid flashover as a result of the accumulation of foreign substances on their surfaces.

13-2.3.2 Inspect contact surfaces for pitting, burning, alignment and pressure. Badly pitted or burned contacts should be replaced.

Examine the fuse unit or fuse tube and renewable element for corrosion of the fuse element or connecting conductors, excessive erosion of the inside of the fuse tubes, discharge (tracking) and dirt on the outside of the fuse tube, and improper assembly that may prevent proper operation. Replace fuse tubes or units showing signs of deterioration.

13-2.3.3 See that bolts, nuts, washers, pins, and terminal connectors are in place and in good condition. Check lock or latch.

Refinish fuse tubes made of organic (Class A) material as required and specified by the manufacturer.

13-2.3.4 Vented expulsion fuses may be equipped with condensers or mufflers to restrict expulsion of gases during operation. They may have a dropout feature that automatically disengages the fuse when it operates. The lower or discharge end of the expulsion fuse may have a sealing disc over the expulsion chamber to prevent entrance of moisture if the fuse is left in an inverted, disconnected position in service. These seals should be inspected to assure that moisture has not entered the interrupting chamber. If the seals are damaged or show evidence of leakage, the fuses should be replaced.

Chapter 14 Rotating Equipment

14-1 General.

14-1.1 The various classes of rotating equipment have many common features in routine maintenance, both electrical and mechanical. The recommendations that follow are of a general nature, and are not intended to cover in detail large or special applications, such as gear pump motors, or those designed for hazardous (classified) locations.

14-1.2 A complete list of the machines in operation, the functions they perform, and the past history of operation form the basis for a schedule of routine maintenance. Frequency of inspection depends on the nature of the service, the hours of operation, and the environment under which the equipment operates. Periodic inspection and appropriate maintenance will assist in making continuous operation of the equipment possible. In some instances disassembly is required for a complete inspection and necessary repairs.

14-2 Safety. The following safety precautions should be observed:

(a) Make sure a machine is dead mechanically and electrically before starting work and properly protected against unintentional re-energization.

(b) Personal protective equipment such as goggles, gloves, aprons, and respirators should be worn when working with solvents.

(c) Great care should be exercised in selecting solvents for any particular task.

(d) Adequate ventilation must be provided to avoid fire, explosion, and health hazards where cleaning solvents are used.

(e) A metal nozzle used for spraying flammable solvents should be bonded to the supply drum and to the equipment being sprayed.

(f) Rubber insulating gloves should be used in connecting and operating high-voltage test instruments.

(g) After tests have been made, discharge stored energy from windings before handling test leads.

14-3 Stator and Rotor Windings. The life of a winding depends upon keeping it as near to its original condition as long as possible. Insulation failure causes immediate outage time. The following points should be carefully examined and corrective action taken during scheduled inspections to prevent operational failures.

14-3.1 Dust and dirt are almost always present in windings that have been in operation under average conditions. Some forms of dust are highly conductive and contribute materially to insulation breakdown as well as restricting ventilation. (*See 14-6.2 on Cleaning.*)

14-3.2 Note evidence of moisture, oil, or grease on the winding and, if necessary, clean the winding thoroughly with a solvent solution. (*See 14-6.2.4 for Solvent Cleaning.*) Generally, after a major cleaning, a drying process is required to restore the insulation to a safe level for operation. (*See 14-6.3 on Drying.*)

14-3.3 Check winding tightness in the slots or on the pole pieces. One condition that hastens winding failure is movement of the coils due to vibration during operation. The effects of varnish and oven treatments so as to fill all air spaces caused by drying and shrinkage of the insulation will maintain a solid winding.

14-3.4 Check insulation surfaces for cracks, crazing, flaking, powdering, or other evidence of need to renew insulation. Usually under these conditions, when the winding is still tight in the slots, a coat or two of air-drying varnish may restore the insulation to a safe value.

14-3.5 Check the winding mechanical supports for insulation quality and tightness, the ring binding on stator windings, and the glass or wire-wound bands on rotating windings.

14-3.6 Examine squirrel-cage rotors for excessive heating, or for discolored or cracked rotor bars, or cracked end rings that may indicate open circuits or high resistance points between the end rings and rotor bars. The symptoms of such conditions are slowing down under load and reduced starting torque. Brazing or welding broken bars or replacing bars should be done only by a qualified person or repair shop.

14-4 Brushes, Collector Rings, and Commutators. In general, observe the machine in operation if possible and note any evidence of maloperation such as sparking, chatter of brushes in the holder, cleanliness, etc., as an aid to inspection repairs later.

14-4.1 Brushes. Successful brush operation depends upon the proper selection and maintenance of the brush most suitable for the service requirements.

14-4.1.1 Check brushes in holders for fit and free play and replace those that are worn down almost to the brush rivet.

14-4.1.2 Tighten brush studs that may have become loose from the drying and shrinking of insulating washers.

14-4.1.3 Examine brush faces for chipped toes or heels and for heat cracks. Replace any that are damaged.

14-4.1.4 Make a check of brush spring pressure using the spring balance method. Readjust the spring pressure in accordance with the manufacturer's instructions.

14-4.1.5 Make sure the brush shunts are properly secured to the brushes and holders.

14-4.1.6 In some instances, if changes have occurred in the operation of equipment since installation, it may be necessary to check the following points that would not ordinarily be disturbed.

(a) Reset brushes at the correct angle.

(b) Reset brushes in the neutral plane.

(c) Properly space brushes on the commutator.

(d) Correctly stagger the brush holders.

(e) Properly space brush holders from the commutator.

(f) Check to ensure that the correct grade of brush as recommended by the manufacturer is being used.

14-4.2 Collector Rings. The surest means of securing satisfactory operation is maintaining the slip-ring surface in a smooth and concentric condition.

14-4.2.1 Check insulation resistance between ring and shaft to detect cracked or defective bushings and collars.

14-4.2.2 A thorough cleaning is usually required, using a solvent cleaner and stiff brush.

14-4.2.3 Check brush holder end play and staggering to prevent grooving the rings during operation.

14-4.2.4 When the rings have worn eccentric with the shaft, the ring face should be machined.

14-4.3 Commutators. In general, sources of unsatisfactory commutation are due to either improper assembly of current collecting parts or faulty operating conditions.

14-4.3.1 Check commutator concentricity with a dial gauge if sufficient evidence indicates that the commutator is out of round. A dial indicator reading of 0.001 inch on high-speed machines to several thousandths of an inch on low-speed machines can be considered normal.

14-4.3.2 Examine commutator surface for high bars, grooving, evidence of scratches or roughness. In light cases, the commutator may be hand stoned, but for extreme roughness, turning of the commutator in the lathe is recommended.

14-4.3.3 Check for high or pitted mica and undercut where deemed advisable.

14-4.3.4 After conditioning a commutator, make sure that it is completely clean, with every trace of copper, carbon, or other dust removed.

See Westinghouse Electric Corporation bibliography reference, *Electrical Maintenance Hints*.

14-5 Bearings and Lubrication.

14-5.1 General. The bearings of all electrical equipment should be subjected to careful inspection at scheduled periodic intervals to assure maximum life. The frequency of inspection is best determined by a study of the particular operating conditions.

14-5.2 Sleeve Bearings.

14-5.2.1 In the older types, the oil should be drained, the bearing flushed, and new oil added at least every year.

14-5.2.2 The new type of sealed sleeve bearings require very little attention since oil level is frequently the only check needed for years of service.

14-5.2.3 Waste packed bearings should be re-oiled every 1000 hours of operation.

14-5.2.4 Check the air gap with a feeler gauge to ensure against a worn bearing that might permit the rotor to rub the laminations. On larger machines, keep a record of these checks. Take four measurements 90 degrees apart at each bearing location and compare with readings previously recorded to permit early detection of bearing wear.

14-5.2.5 Bearing currents on larger machines are usually eliminated by installing insulation under the pedestals or brackets. Elimination of this circulating current prevents pitting the bearing and shaft. From a maintenance standpoint, make sure that the pedestal insulation is not short circuited by metal thermostat or thermometer leads, or by piping.

14-5.3 Ball and Roller Bearings.

14-5.3.1 External inspection at the time of greasing will determine whether the bearings are operating quietly and without undue heating.

14-5.3.2 The bearing housings may be opened to check the condition of the bearings and grease. The bearing and housing parts should be thoroughly cleaned and new grease added.

14-5.3.3 Where special instructions regarding the type or quantity of lubricant are recommended by the manufacturer, they should be followed. In all cases, standard greasing practices should be strictly adhered to.

14-5.4 Kingsbury Thrust Bearings. Established lubrication practice for sleeve bearings applies in general for thrust bearings.

14-6 Cleaning and Drying Insulation Structures.

14-6.1 General. Various methods for cleaning are available, and the method used will depend on the kind of dirt to be removed and whether or not the apparatus is to be returned to use immediately. Drying after a solvent or water cleaning is necessary. Insulating testing is also necessary to determine whether the insulation has been properly reconditioned.

14-6.2 Cleaning. The methods of cleaning electrical insulation include:

14-6.2.1 Wiping off the dirt with a clean, dry cloth is usually satisfactory if the apparatus is small; the surfaces to be cleaned are accessible; and dry dirt only is to be removed. Waste should not be used as lint will adhere to the insulation and act as a further dirt-collecting agent.

14-6.2.2 For removal of loose dust, dirt, and particles, the use of suction is preferable to blowing out with compressed air since there is less possibility of damage to the insulation and less chance of getting conducting or other harmful particles into areas that may later result in damage during operation.

14-6.2.3 Compressed air blowing may be required where dirt cannot be vacuumed. Care should be taken that the dirt is not blown out of one machine into another. Air pressure should not be greater than 30 lb. It should be dry, and directed in such a manner as to avoid further closing ventilation ducts and recesses in insulation.

14-6.2.4 Accumulated dirt containing oil or grease requires a solvent to remove it. A rag barely moistened (not wet) with a nonflammable solvent may be used for wiping. Avoid liquid solvent spraying that can carry conducting contaminants into critical areas to produce shorts and grounds.

14-6.2.5 Apparatus that has been clogged with mud from dust storms, floods, or other unusual conditions will require a thorough water washing, usually with a hose with pressure not exceeding 25 psi. After cleaning, the surface moisture should be removed promptly to keep the amount of water soaked up by the insulation to a minimum.

14-6.2.6 Silicone-treated windings require special treatment, and the manufacturer should be contacted for advice.

14-6.3 After cleaning, storing, or shipping, apparatus should be dried before being placed in operation if tests indicate that the insulation resistance is below a safe minimum level. Two general methods are commonly used — external or internal heat; external heat is preferred since it is the safer application.

14-6.3.1 Where available, low pressure steam may be used through radiators or steam pipes placed below the end windings with a temporary built-in enclosure to hold the heat.

14-6.3.2 Forced hot air may be heated electrically, by steam, or by open fire. This method is usually inefficient and costly unless built into the original installation.

14-6.3.3 Electric space heaters or infrared lamps may be used. They should be distributed so as not to overheat the insulation.

14-6.3.4 Coil insulation may be dried by circulating current through the winding. There is some hazard since the heat generated in the inner parts is not readily dissipated. This method should be followed only under competent supervision.

14-6.3.5 For synchronous motors, the short-circuit method is sometimes used by shorting the armature windings and driving the rotor, applying sufficient field excitation to give somewhat less than full-load armature current.

14-7 General Overhaul. When indicated by visual inspection or tests, the equipment should be disassembled, have the winding cleaned, dried and reinsulated or dipped and baked and the bearings checked and relubricated. Rewinding or other repair decisions should be made at this time.

14-8 Testing. (*See Chapter 18 for Recommended Tests.*)

14-9 Records. Sample record forms are shown in Appendix G.

Chapter 15 Lighting

15-1 General. A planned maintenance program is an essential part of any initial lighting design and recommendation. The maintenance of lighting systems is aimed at preserving the light producing capability at the original design level. Dirt and lamp aging are the two major factors that reduce the light output.

15-2 Cleaning.

15-2.1 Lighting equipment — lamps, reflectors, and lens — should be cleaned periodically. The cleaning interval depends on the amount and type of dirt in the air, although the design of the luminaire will affect the rate at which dust collects. Periodic light meter readings may be taken and cleaning intervals established when the lighting level falls 15 to 20 percent.

15-2.2 Washing is better than wiping and the washing solution should be in accordance with the instructions of the luminaire manufacturer. Strong alkaline or abrasive cleaners should be avoided.

15-3 Relamping.

15-3.1 The longer a lamp remains in service, the less light it produces. The different types of lamps — filament, fluorescent, or high-intensity discharge — depreciate at different rates. Since their life expectancy is also different, replacement intervals will vary.

15-3.2 The two general relamping procedures are spot relamping and group relamping. Spot relamping is the replacement of individual lamps as they fail. Group relamping is the replacement of all the lamps at a time interval varying from 50 to 80 percent of rated-average life, or when the light output falls below the desired level. It is economical to wash the fixtures at the time of replacement. It is also advantageous to inspect the sockets, hangers, reflectors, and lens at the time of lamp replacement. General replacement recommendations and study results are available from the major lamp manufacturers.

15-3.3 Replacement lamps should be of the same type, color, wattage, and voltage as those being replaced.

15-4 Voltage.

15-4.1 Lamps are designed to provide rated-average life expectancy and light output at the rated operating voltage and wattage.

15-4.2 A filament lamp operating at 5 percent overvoltage will have its life expectancy reduced almost 50 percent, while the light output will be increased by about 18 percent. Five percent undervoltage operation will increase lamp life to about 195 percent, and light output will be reduced to about 84 percent.

15-4.3 Fluorescent lamp ballasts are designed for operation at 118, 208, 236, 277, or 460 volts. The ranges of permissible variations are 110-125, 199-216, 220-250, 260-290, and 440-480 volts. Higher voltages will shorten lamp and ballast life, while lower voltage will also shorten lamp life and may cause uncertain starting. Frequent starting will shorten lamp life.

15-4.4 With the commonly encountered lamps and circuits, continuous flashing or blinking will destroy the starter, shorten lamp life, and may damage the ballast. Whenever possible, replacement ballasts should be of the class "P"-rated type that have internal temperature-sensitive overload protection. This is not always possible as "P" ballasts may not operate satisfactorily in equipment that is otherwise satisfactory. Original type ballasts should be used if available. Replacement starters should be of the type having an overload circuit opening device.

15-4.5 Some high-intensity discharge lamp ballasts are provided with taps to accommodate variations from rated voltage. Line voltage higher than the rated voltage will shorten ballast and lamp life, while lower voltages will reduce light output and may cause uncertain starting.

Chapter 16 Wiring Devices

16-1 Attachment Plugs, Cord Connectors, and Receptacles.

16-1.1 General. This section covers the maintenance of attachment plugs, cord connectors, and receptacles rated not more than 200 amperes nor more than 600 volts.

16-1.2 The connection of equipment to supplies of different electrical ratings of current, voltage, phase, or frequency can be hazardous or can cause damage to equipment. Therefore, attachment plugs, cord connectors, and equipment are provided with different ratings and configurations to prevent hazardous interconnection.

NOTE: See Appendices H-1 and H-2 for ANSI C73 Configuration Chart.

16-1.3 The use of these devices for the connection of equipment provides for rapid removal and replacement and facilitates relocation.

16-1.4 Up to 60 amperes, all devices are tested for the capability of being connected or disconnected under full load. Devices rated above 60 amperes are marked as to whether they are listed for this mode of operation.

16-1.5 Use of these devices to disconnect some equipment under some load conditions such as welders and running or stalled motors may be hazardous. Other load interrupting means intended for this purpose should be used.

16-2 Attachment Plugs and Connector Bodies.

16-2.1 Assure that cord clamps and other strain-relief fittings are tight and that the outer cord jacket is completely within the clamping area.

16-2.2 Wire terminations on attachment plugs should be covered by insulating discs or the device should be replaced with a dead-front type. Abnormal heating on the plug surface may be caused by loose terminations, overloading, high ambients, or equipment malfunction. The assembly of individual conductors to terminals should be checked periodically. Individual conductor strands must be properly confined and terminations made tight. Conductor strands should not be solder-dipped since this may cause overheating.

16-2.3 If the attachment plug or connector body is cracked or distorted or pieces are missing or damaged, or if the blades, prongs, or contacts are bent or missing, the device should be replaced. If this is a recurring problem, the device should be replaced with a type suitable for the environment in which it is used. For special applications and environments such as wet locations, highly corrosive environments, and high temperature locations, special service devices specifically intended for the purpose should be used.

16-2.4 Attachment plugs should fit firmly when inserted into the mating connector or receptacle. If accidental disengagement of the plug is a recurring problem, the connector or receptacle should be tested to assure that adequate contact pressure is present. When continuity of service is essential, consideration may be given to the installation of a locking-type device.

16-2.5 Assure proper polarity of all connections.

16-2.6 The green equipment grounding conductor of the cord must be attached to the grounding terminal of the device.

16-3 Receptacles.

16-3.1 If the receptacle is badly worn, cracked, or broken, or if contacts are exposed, the receptacle should be replaced.

16-3.2 Receptacle contacts must hold and retain inserted plugs firmly. If accidental disengagement of the plug from the receptacle is a recurring problem, the receptacle should be replaced. When continuity of service is essential, consideration should be given to the installation of a locking-type device.

16-3.3 Check to assure proper wire connections on receptacles and proper polarity of power connections including the integrity of the equipment ground.

16-3.4 When replacing 15- and 20-ampere nongrounding-type receptacles, grounding-type receptacles should be installed and, where used, must be grounded.

16-3.5 If there is abnormal heating on the receptacle face, check for loose terminations and correct or replace. If there is arc-tracking or evidence of burning of the device or other damage, it should be replaced.

16-4 Adapters.

16-4.1 Adapters between locking and nonlocking configurations provide flexibility in obtaining power for maintenance functions. However, adapters should not be used to bypass the equipment ground, nor should adapters with pigtails be used.

16-5 General-Use Snap Switches.

16-5.1 AC-DC (T-Rated) switches should not be used to control inductive loads such as fluorescent lighting or motors exceeding 50 percent of the switch rating. AC-only switches may control up to 100 percent of their rating for inductive loads or 80 percent of their rating for motor loads.

16-5.2 If the switch is broken or the mechanism does not function in a normal manner, the switch should be replaced. Where repeated abuse is incurred, consideration should be given to relocating the switch or replacing it with a switch having a guarded operating means or a switch with a low profile.

16-5.3 The switch must be firmly fastened to the box to assure electrical and mechanical integrity.

16-5.4 If there is evidence of abnormal heating, the switch should be checked for loose terminals or switch malfunction and corrected or replaced.

16-6 Cover Plates.

16-6.1 All switches and receptacles should be installed with wall plates or covers suitable for the environment and location.

16-6.2 Cracked, bent, or broken wall plates or spring doors or covers should be replaced.

16-6.3 Boxes. Boxes used for the containment of receptacles and switches should be rigidly secured in place. Locknuts and conduit fittings should be made up tight and proper box-fill of conductors should be observed. Closures should be placed in unused knock-out holes. Where boxes, particularly the surface-mounted type, sustain repeated abuse, consideration should be given to flush-mounting or additional guarding means.

16-7 Pin and Sleeve Devices.

16-7.1 Heavy-duty Industrial-type Plugs, Cord Connectors, and Receptacles.

16-7.1.1 Scope. This section covers the maintenance of heavy-duty industrial-type plugs, cord connectors, and receptacles rated not more than 400 amperes nor more than 600 volts.

16-7.1.2 General. Plugs, cord connectors, and receptacles of this type are provided with different ratings and polarizations to prevent hazardous interconnection of different current ratings, voltages, or frequencies. Devices connected to circuits having different voltages, frequencies, or type of current on the same premises should not be interchangeable.

Noninterchangeability is accomplished in these products by at least two methods. The first is the size and location of the contacts. The second is accomplished by keying arrangements of the plug sleeve and receptacle housing. By varying these parameters, sufficient variations can be obtained to accomplish noninterchangeability.

A detailed plan should be prepared specifying the devices based first on performance requirements and then defining the specific configuration for each voltage, amperage, and frequency in use on the premises.

The use of these devices for the connection of equipment provides for rapid removal and replacement and facilitates relocation of electrical equipment.

Most of these assemblies are designed and listed to disconnect the equipment under full-load or locked-rotor currents. If they are not suitable, other load-interrupting means, such as interlocked receptacles, should be used.

16-7.1.3 Plugs. Assure that cord clamps and strain-relief fittings are tight and that the outer cord jacket is completely within the clamping area.

16-7.1.4 Abnormal heating on the plug surface may be caused by loose terminations, overloading, high ambients, or equipment malfunction. Insulators and contacts should be visually inspected for discoloration of the insulator or pitting of contacts. Inspection of other parts should be initiated if discoloration or pitting is observed. Periodically check the assembly of individual conductors to terminals. Individual conductor strands should be properly confined and terminations made tight. Conductor strands should not be soldered when used with binding head screws since this may cause overheating.

16-7.1.5 If the plug or connector housing or interior is cracked, distorted, or pieces are missing, or damaged, or if the pins or contacts are bent, missing or discolored, the complete interior should be replaced. For particularly adverse environments, such as highly corrosive environments, high-temperature locations, or hazardous (classified) locations, devices specifically intended for the purpose should be used.

If the receptacle or plug insulation is cracked, broken, or discolored, the defective parts should be replaced.

Receptacle contacts must retain inserted plugs firmly. Corroded, deformed, or mechanically damaged contacts should be replaced. Check for proper wire connections on receptacles and proper polarity of power connections including the integrity of the equipment ground.

If there is abnormal heating of the receptacle, plug, or connector insulation, check for loose terminations or insufficient pressure between contacts and correct or replace. If there is arc tracking or evidence of burning of the insulation or other damage, it should be replaced.

16-8 Connector and Receptacle.

16-8.1 Plugs should fit firmly when inserted into the mating connector or receptacle. Insufficient mating force can result in contact erosion caused by arcing of the contacts or accidental disengagement. The connector or receptacle should be checked to assure that adequate contact pressure is present. The complete interior should be replaced if there is discoloration of the housing or severe erosion of the contact.

When continuity of service is essential, consideration may be given to the installation of a mechanically held or interlocked assembly.

16-8.2 The equipment grounding conductor (green) of the cord must be attached to the grounding terminal of the device thereby assuring grounding continuity.

16-8.3 The face of the receptacle, plug, or connector should occasionally be thoroughly cleaned.

16-8.4 Cracked, bent, or broken spring doors or covers should be replaced.

16-8.5 All mounting and assembly screws should be present and checked to assure that they are tight since they may provide grounding, prevent the entrance of adverse environmental products, and provide cable retention.

16-8.6 All gaskets, if used, should be inspected to determine if they are present and maintain the integrity of the enclosure.

16-8.7 To assure proper selection of replacement parts, the nameplates should be kept clean and legible, and instructions supplied with the product maintained on file, together with a list of the manufacturer replacement parts.

16-8.8 Since the grounding circuit may include the external shell, pin, and sleeve devices should not be painted.

16-8.9 Control contacts are occasionally used in conjunction with power pins. These control contacts should be inspected to assure that they make last and break first.

16-8.10 Devices used in hazardous (classified) locations require some additional inspections. All mechanically and electrically interlocked plugs and receptacles should be inspected for proper operation and for excessively worn or broken parts. Replace as required. All parts and surfaces of these devices should be clean and free of foreign material or corrosion. Flame paths should be inspected to assure safe gaps are not exceeded and no scratches are on the ground joints. All screws holding the receptacle to the body should be installed and tight. Covers and threaded openings should be properly tightened. These devices should be checked to make sure that the plug and receptacle marking agree with the present classification of the area in regard to the Class, Group, and Division.

Chapter 17 Portable Electrical Tools and Equipment

17-1 General.

17-1.1 Dependable performance and long service life of power tools is becoming more important as the need for mechanization and the use of these tools increases. A plant's entire inventory of portable tools can be kept in top operating condition for maximum production quality and cost efficiency with a planned routine and periodic inspection.

17-1.2 There are many and varied types of portable power tools and many and varied causes of power tool failure. Because of this, the procedures can be general recommendations only. Variations will exist and will depend on the type of tool and the particular conditions of use. It is strongly recommended that the information on proper use and maintenance given in the tool manufacturer's use and care manual, supplied with each tool, be carefully followed.

17-1.3 Periodic electrical testing will uncover many operating defects, and their immediate correction will ensure safe operation and prevent breakdown and more costly repairs. This testing and the related maintenance should be systematic. A visual inspection before and after each use when issued and when returned to the tool crib should be required.

17-2 Employee Training.

17-2.1 An important part of preventive maintenance is employee training in the proper care and use of portable power tools. Employees should be given instructions in selecting the proper tool for the job and the limitations of the tool. Overloading may be caused by using an underpowered tool for the work load.

17-2.2 Employees should be trained to recognize obvious defects such as cut, frayed, spliced, or broken cords, cracked or broken attachment plugs, and missing or deformed grounding prongs. Such defects should be reported immediately.

17-2.3 Employees should be instructed to report all shocks, no matter how minor, immediately and to cease using the tool. Tools causing shocks should be examined and repaired before further use.

17-3 Maintenance. The following are general recommendations. The best source for maintenance information is the original manufacturer.

17-3.1 Periodic Inspection of Crucial Wear Points. Brushes and commutators should be inspected periodically. This is easily accomplished by removal of brush holder plugs or inspection plates depending on the construction of the tool. Brushes worn down to 50 percent of their original size should be replaced. When making brush replacement, always be sure to use manufacturer's original equipment.

17-3.2 Excessive Dirt Accumulation. All universal motors are fan ventilated to prevent excessive heat. Even though many tools have filters and deflectors to prevent destructive material from damaging the motor, a small amount of it will pass through. Excessive build-up affects the brush operation and reduces air volume necessary to cool the motor. When required, the tool should be blown out with low-pressure, dry-compressed air when used in a normal environment. More frequent specialized maintenance may be required if the atmosphere is heavy in abrasives or conducting dusts.

17-3.3 Insufficient or Improper Lubrication. Lubricant inspection is needed at frequent intervals to ensure sufficient lubricant to prevent wear to mechanical parts. Dirty lubricants should be removed and replaced. Since lubricant varies from tool to tool, it is recommended that proper lubricant be obtained from the manufacturer or the manufacturer's distribution outlet.

Manufacturers carefully match lubricants to be compatible with speeds, heat, seals, bearings, and pressure to ensure long gear and mechanism life. Substitutions may damage the tool and invalidate the warranty.

The wrong amount of lubricant can cause serious problems. Too little, of course, means that surfaces are not adequately covered and excess wear will result. Too much lubricant can cause excess pressure in the gear case and eventually ruins seals.

17-4 Cord and Attachment Plug Care.

17-4.1 The cord of an electric power tool is the life line. It should be kept free of oil, grease and other material that may ruin the rubber cover. Avoid tangling knots or dragging across sharp surfaces. Do not use it as a tow line to carry or drag the tool.

17-4.2 All power tools, unless they are double insulated and so marked, are required to be grounded through an additional grounding conductor in the cord and the grounding prong of the attachment plug. The integrity of this grounding circuit is necessary for the protection of life and should be visually inspected before each use. Experience has shown that the grounding prongs of attachment caps are frequently cut off for use in ungrounded receptacles. This practice should not be permitted.

17-4.3 If a cord is cut, broken, spliced, or frayed, or the attachment plug is damaged or the grounding prong removed, it should be immediately withdrawn from service until it can be repaired. Cords may be replaced in their entirety, or a damaged cord can be repaired by cutting out the damaged portion and applying a plug and connector to rejoin the two sections. Replacement cords should be of the same type and conductor size and suitable for use.

17-4.4 To avoid accidents, the green conductor must always, and only, be used to connect the frame of the tool to the grounding prong of the attachment plug. It should not be used for any other purpose.

17-5 Extension Cords. Before placing extension cords in service, the plug and connector should be checked for proper polarity and the grounding conductor should be tested for continuity and intregity. Extension cords of the proper conductor size should be used to avoid excessive voltage drop that may result in poor operation and possible damage to the tool. *(See Table 17-5 for recommended sizes.)*

17-6 Major Overhauls. Major overhauls and repairs should be performed by the manufacturer; however, large power-tool users who prefer to do their own repairs and overhaul should obtain necessary parts, schematics, connection diagrams, lubricant charts, and other technical information from the manufacturer.

17-7 Leakage Current Testing. Portable and cord-connected equipment should be periodically tested for the amount of leakage current present to help ensure against shock hazards.

Table 17-5 Size of Extension Cords for Portable Electric Tools

Based on current equivalent to 150 percent of full load of tool and a loss in voltage of not over 5 volts

Extension Cord Length (Ft.)	Nameplate Ampere Rating											
	0-2.0		2.1-3.4		3.5-5.0		5.1-7.0		7.1-12.0		12.1-16.0	
	115V	230V	115V	230V	115V	230V	115V	230V	115V	230V	115V	230V
25	18	18	18	18	18	18	18	18	16	18	14	16
50	18	18	18	18	18	18	16	18	14	16	12	14
75	18	18	18	18	16	18	14	16	12	14	10	12
100	18	18	16	18	14	16	12	14	10	12	8	10
200	16	18	14	16	12	14	10	12	8	10	6	8
300	14	16	12	14	10	14	8	12	6	10	4	6
400	12	16	10	14	8	12	6	10	4	8	4	6
500	12	14	10	12	8	12	6	10	4	6	2	4
600	10.	14	8	12	6	10	4	8	2	6	2	4
800	10	12	8	10	6	8	4	6	2	4	s591	2
1000	8	12	6	10	4	8	2	6	1	4	0	2

NOTE — If voltage is already low at the source (outlet), have voltage increased to standard, or use a larger cord than listed in order to minimize the total voltage drop.

Chapter 18 Testing and Test Methods

18-1 General. This chapter covers the tests ordinarily used in the field to determine the condition of various elements of an electrical power-distribution system. The data obtained in these tests provide information that is used to:

(a) Determine whether any corrective maintenance or replacement is necessary or desirable.

(b) Ascertain the ability of the element to continue to perform its design function adequately.

(c) Chart the gradual deterioration of the equipment over its service life.

18-2 Acceptance Tests and Maintenance Tests.

18-2.1 Acceptance Tests. Acceptance tests are tests that are performed on new equipment, usually after installation, prior to energization. These tests are performed to determine whether a piece of equipment is in compliance with the purchase specification and design intent and also to establish test benchmarks that can be used as reference during future tests. Acceptance tests are also valuable in assuring that the equipment has not been subjected to damage during shipment or installation. In addition to the tests that are performed, an acceptance program should include a comprehensive visual inspection and an operational check of all circuitry and accessory devices.

18-2.2 Routine Maintenance Tests. Routine maintenance tests are tests that are performed at regular intervals over the service life of equipment. These tests are normally performed concurrently with preventive maintenance on the equipment.

18-2.3 Special Maintenance Tests. Special maintenance tests are tests performed on equipment that is thought or known to be defective, or equipment that has been subjected to conditions that could possibly adversely affect its condition or operating characteristics. Examples of this would be cable fault-locating tests or tests performed on a circuit breaker that has interrupted a high level of fault current.

18-2.4 Pretest Circuit Analysis. An analysis of the circuit to be tested should be made prior to the testing to assess the potential meaning of the test results.

18-3 As-Found and As-Left Tests.

18-3.1 As-Found Tests. As-Found tests are tests performed on equipment on receipt or after it has been taken out of service for maintenance, but before any maintenance work is performed.

18-3.2 As-Left Tests. As-Left tests are tests performed on equipment after preventive or corrective maintenance, immediately prior to placing the equipment back in service.

18-3.3 Correlation of As-Found and As-Left Tests. When equipment is taken out of service for maintenance, it is often useful to perform both As-Found and As-Left tests. The As-Found tests will show any deterioration or defects in the equipment since the last maintenance period and, in addition, will indicate whether corrective maintenance or special procedures should be taken during the maintenance process. The As-Left tests will indicate the degree of improvement in the equipment during the maintenance process and will also serve as a benchmark for comparison with the As-Found tests during the next maintenance cycle.

18-4 Frequency of Tests. Most routine testing can best be performed concurrently with routine preventive maintenance, since a single outage will serve to allow both procedures. For this reason, the frequency of testing will generally coincide with the frequency of maintenance. The optimum cycle depends on the use to which the equipment is put and the operating and environmental conditions of the equipment. In general, this cycle can range from six months to three years, depending on the above criteria. The difficulty of obtaining an outage should never be a factor in determining the frequency of testing and maintenance. Equipment for which an outage is difficult to obtain is usually the equipment that is most vital in the operation of the electrical system. Consequently, a failure of this equipment would most likely create the most problems relative to the continued successful operation of the system. In addition to routine testing, tests should be performed any time equipment has been subjected to conditions that could possibly have caused it to be unable to continue to perform its design function properly.

18-5 Special Precautions and Safety.

18-5.1 Many tests on electrical equipment involve the use of high voltages and currents that are dangerous, both from the standpoint of being life-hazards to personnel and because they are capable of damaging or destroying the equipment under test. Adequate safety rules must be instituted and practiced to prevent injury to personnel, both test personnel and others who might be exposed to the hazard. Also, the test procedures used should be designed to assure that no intentional damage to equipment will result from the testing process.

18-5.2 It must be recognized, as the name implies, that "over-potential" or "high-potential" testing is intended to stress the insulation structure above that of normal system voltage. The purpose of the test is to establish the integrity of the insulation to withstand voltage transients associated with switching and lightning surges, and hence reduce the probability of in-service equipment failures. Direct voltage over-potential testing is generally considered a controlled, nondestructive test in that an experienced operator, utilizing a suitable test set, can often detect marginal insulation from the behavior of measured current. It is therefore possible, in many cases, to detect questionable insulation and plan for replacement without actually breaking it down under test.

Unfortunately, some insulations may break down with no warning. Plans for coping with this possibility should be included in the test schedule.

18-5.3 Low-voltage insulation testing may generally be done at the beginning of the planned maintenance shutdown. In the event of an insulation failure under test, maximum time would be available for repair prior to the scheduled plant start-up. Equipment found in wet or dirty condition should be cleaned and dried before high potential testing is done or a breakdown may damage the equipment.

18-5.4 Low-voltage circuit breakers, which require very high interrupting ratings, are available with integral current-limiting fuses. Although the fuse size is selected to override without damage to the time-current operating characteristic of the series trip device, it is desirable to bypass or remove the fuse prior to applying simulated overload and fault current.

18-6 Qualifications of Test Operators. If a testing program is to provide meaningful information relative to the condition of the equipment under test, then the person evaluating the test data must be assured that the test was conducted in a proper manner and that all of the conditions that could affect the evaluation of the tests were considered and any pertinent factors reported. The test operator, therefore, must be thoroughly familiar with the test equipment used in the type of test to be performed, and also sufficiently experienced to be able to detect any equipment abnormalities or questionable data during the performance of the tests.

18-7 Test Equipment. It is important in any test program to have the proper equipment to perform the required tests. In general, any test equipment used for the calibration of other equipment should have an accuracy at least twice the accuracy of the equipment under test. The test equipment should be maintained in good condition and should be used only by qualified test operators. All test equipment should be calibrated at regular intervals to assure the validity of the data obtained.

In order to get valid test results, it may be necessary to regulate the power input to the test equipment for proper waveform and frequency and to eliminate voltage surges.

18-8 Use of Forms. If a testing and maintenance program is to provide optimum benefits, it will be found to be useful to record all testing data and maintenance actions on test circuit diagrams and forms that are complete and comprehensive. It is often useful to record both test data and maintenance information on the same form. A storage and filing system should be set up for these forms that will provide efficient and rapid retrieval of information regarding previous testing and maintenance on a piece of equipment. A well-designed form will also serve as a guide or a checklist of inspection requirements. Samples of typical forms that can be used are included in Appendix G.

18-9 Insulation Testing.

18-9.1 General.

18-9.1.1 Insulation is the material between points of different potential in an electrical system that prevents the flow of electricity between those points. Insulation materials can be in the gaseous, liquid, or solid form. A vacuum is also a commonly used insulation medium. The failure of the insulation system is the most common cause of problems in electrical equipment. This is true on both high-voltage and low-voltage systems. Insulation tests are tests used to determine the quality or condition of the insulation systems of electrical equipment. Both alternating current and direct current are used in insulation testing.

18-9.1.2 Reasons for Insulation Failure. Liquid and solid insulating materials with organic content are subject to natural deterioration due to aging. This natural deterioration is accelerated by excessive heat and moisture. Heat, moisture, and dirt are the principal causes of all insulation failures. Insulation can also fail due to chemical attack, mechanical damage, sunlight, and excessive voltage stresses.

18-9.2 DC Testing: Components of Test Current. When a dc potential is applied across an insulation, the resultant current flow is composed of several components as follows:

(a) Capacitance charging current.

(b) Dielectric absorption current.

(c) Surface leakage current.

(d) Partial discharge (corona current).

(e) Volumetric leakage current.

The capacitance charging current and the dielectric absorption current decrease as the time of application of the voltage increases. The test readings of resistance or current should not be taken until these two currents have decreased to a low value and will not significantly affect the reading. The time lapse between the application of voltage and the taking of the reading should be reported as part of the test data. The surface leakage current is caused by conduction on the surface of the insulation between the points where the conductor emerges from the insulation and points of ground potential. This current is not desired in the test results (except for As-Found tests) and can be eliminated by carefully cleaning the leakage paths described. Corona current occurs only at high values of test voltage. This current is caused by the overstressing of air at sharp corners or points on the conductor. This current is not desired in the test results and can be eliminated by installing stress-control shielding at such points during the test. Volumetric leakage current is the current that flows through the volume insulation itself. It is the current that is of primary interest in the evaluation of the condition of the insulation.

18-9.2.1 Insulation-Resistance Testing.

(a) In an insulation-resistance test, an applied voltage, from 100 to 5,000 volts, supplied from a source of constant potential, is applied across the insulation. The usual potential source is a megohmmeter, either hand or power operated, that indicates the insulation resistance directly on a scale calibrated in megohms. The quality of the insulation is evaluated based on the level of the insulation resistance.

(b) The insulation resistance of many types of insulation is quite variable with temperature, so the data obtained should be corrected to the standard temperature for the class of equipment under test. Some published charts are available for this purpose.

(c) The megohm value of insulation resistance obtained will be inversely proportional to the volume of insulation being tested. As an example, a cable 1,000 ft (304.8 m) long would be expected to have one-tenth the insulation resistance of a cable 100 ft (30.48 m) long if all other conditions were identical.

(d) The insulation-resistance test is relatively easy to perform and is a useful test used on all types and classes of electrical equipment. Its main value lies in the charting of data from periodic tests, corrected for temperature, over the life of the equipment so that deteriorative trends might be detected.

18-9.2.2 Dielectric Absorption.

(a) In a dielectric absorption test, a voltage supplied from a source of constant potential is applied across the insulation. The range of voltages used is much higher than the insulation resistance test and can exceed 100,000 volts. The potential source can be either a megohmmeter as described in 18-9.2.1(a), or a high-voltage power supply with an ammeter indicating the current being drawn by the specimen under test. The voltage is applied for an extended period of time, from 5 to 15 minutes, and periodic readings are taken of the insulation resistance or leakage current.

(b) The test data is evaluated on the basis that if an insulation is in good condition, its apparent insulation-resistance will increase as the test progresses. Unlike the insulation resistance test, the dielectric absorption test results are independent of the volume and the temperature of the insulation under test.

18-9.2.3 Polarization Index. The Polarization Index is a specialized application of the dielectric absorption test. The index is the ratio of insulation resistance at two different times after voltage application, usually the insulation resistance at ten minutes to the insulation resistance at one minute. The use of Polarization Index testing is usually confined to rotating machines, cables, and transformers. A Polarization Index less than 1.0 indicates that the equipment needs maintenance before being placed in service. References are available for polarization indexes for various types of equipment.

18-9.2.4 High Potential Testing.

(a) A high potential test consists of applying voltage across an insulation at or above the dc equivalent of the 60 Hertz operating crest voltage. This test can be applied either as a dielectric absorption test or a step-voltage test.

1. When applied as a dielectric absorption test, the maximum voltage is applied gradually over a period of from sixty to ninety seconds. The maximum voltage is then held for five minutes with leakage current readings being taken each minute.

2. When applied as a step-voltage test, the maximum voltage is applied in a number of equal increments, usually not less than eight, with each voltage step being held for an equal interval of time. The time interval between steps should be long enough to allow the leakage current to reach stability, approximately one or two minutes. A leakage current reading is taken at the end of each interval before the voltage is raised to the next level. A linear increase in leakage current is expected and it should stabilize or decrease from the initial value at each step. A plot of test voltage versus leakage current or insulation resistance is drawn as the test progresses. A nonlinear increase in leakage current may indicate imminent failure and the test should be discontinued. After the maximum test voltage is reached, a dielectric absorption test may be performed at that voltage, usually for a five-minute period.

3. At the end of each test, turn the test equipment control to zero voltage and monitor the voltage. When the voltage is reduced to 20 percent, or lower, of the maximum test voltage, ground the metallic components in accordance with test procedures or for at least 30 minutes.

(b) Before equipment insulation is tested, it should be cleaned, inspected, and repaired as found necessary to minimize leakage currents. The same action should be taken for cable terminations. Surge arresters must be disconnected.

When testing cables, all transformers, switches, fuse cutouts, switchgear, etc., should be disconnected wherever practicable. Thus, if significant leakage currents are encountered, it will be known that these currents are in the cable insulation and not in equipment connected thereto. Further, if such disconnection is impractical, it may be necessary to limit the maximum test voltage to the level that such equipment can withstand without damage.

High leakage currents in cables may be due to improper preparation of their ends before the cable terminations were installed, thereby allowing high surface leakage across them.

(c) The maximum permissible test voltages for acceptance tests performed on cables are listed in the Insulated Power Cable Engineers Association's (IPCEA) standards for rubber, thermoplastic, and varnished cloth insulations, and in the Association of Edison Illuminating Companies (AEIC) standards for solid-type impregnated-paper insulation. Ordinarily, routine maintenance tests are conducted with a maximum test voltage at or below 75 percent of the maximum test voltage permitted for acceptance testing. (*See IEEE Guide for Making High-Direct-Voltage Tests on Power-Cable Systems in the Field [P400].*)

(d) Care should be taken in choosing the appropriate test voltage for routine maintenance tests on cables that have been in service for longer periods. If the level selected is too low, marginal weak spots may not be revealed; if the level is too high, damage to the insulation may result.

The test voltage should be applied from phase-to-ground on each conductor with the other conductors, the shields, and metallic jackets also connected to ground. The dc to ac (RMS) test voltage ratios ordinarily used are as follows:

CABLE INSULATION	RATIO
Rubber or Rubberlike, Ozone Resisting	3.0 to 1
Rubber or Rubberlike, Other than Ozone Resisting	2.2 to 1
Impregnated Paper, Solid Type	2.4 to 1
Varnished Cloth	2.0 to 1
Polyethylene	3.0 to 1

(e) When the step-voltage type of test is used, the condition of the cable is evaluated on the basis of (1) the absolute values of insulation resistance, (2) the slope of the curve of voltage versus insulation resistance, and (3) whether or not a significant downward "knee" appears in the curve at the higher levels of test voltage.

18-9.3 AC Testing.

18-9.3.1 High Potential Testing. AC high potential tests are made at voltages above the normal system voltage for a short time, such as one minute. The test voltages to be used vary depending on whether the device or circuit is low or high voltage, a primary or control circuit, and whether it was tested at the factory or in the field. Manufacturer's instructions and the applicable standards should be consulted for the proper values.

18-9.3.2 Insulation Power Factor Testing.

(a) The power factor of an insulation is the cosine of the angle between the charging current vector and the impressed voltage vector when the insulation system is energized with an ac voltage. In other words, it is a measure of the energy component of the charging current. The term "power factor testing" means any testing performed in order to determine the power factor of an insulation system. For low values of power factor, the dissipation factor can be assumed to be the same as the power factor. Power factor testing is a useful tool in evaluating the quality of insulation in power, distribution and instrument transformers, circuit breakers, rotating machines, cables, regulators, and insulating liquids. The equipment to be tested should be isolated from the rest of the system, if practical, and all bushings or terminations should be cleaned and dried. The test should be conducted when the relative humidity is below 70 percent and when the insulation system is at a temperature above 32°F (0°C). Data obtained at relative humidity above 70 percent must be interpreted to recognize the higher humidity.

(b) The test equipment used should be such that the power factor or dissipation factor may be read directly or such that the charging volt-amperes and the dielectric losses may be read separately so that a ratio might be computed. The test equipment should also have sufficient electromagnetic interference cancellation devices or shielding to give meaningful test results even when used in an area of strong interference, such as an energized substation. The test equipment should be able to produce and maintain a sinusoidal wave shape while performing the test at 60 Hertz, and of sufficient capacity and voltage range to perform the test at a minimum voltage of 2,500 volts or the operating voltage of the equipment under test, whichever is lower, but in no case less than 500 volts.

(c) On transformer tests, the power factor of (1) each winding with respect to ground and (2) each winding with respect to each other winding should be obtained. In addition, tests should be made of each bushing with a rated voltage above 600 volts, either using the power factor or capacitance tap if the bushing is so equipped or by use of a "hot-collar" test using a test electrode around the outside shell of the bushing.

(d) On circuit breakers, the power factor of (1) each line-side and load-side bushing assembly complete with stationary contacts and interrupters, with the circuit breaker open, and (2) each pole of the circuit breaker with the breaker closed should be obtained. In addition, tests should be made of each bushing as described above. Air magnetic circuit breakers should be tested both with and without arc chutes.

(e) On ac rotating machines, the neutral connection on the stator should be removed and a test of each winding with respect to the other two windings and ground should be obtained.

(f) For cables, the power factor of each conductor with respect to ground should be obtained and a hot-collar test should be made of each pothead or termination. Power factor testing of insulating oil should be performed in accordance with ASTM D924.

(g) Evaluation of the data obtained should be based on (1) industry standards for the particular type of equipment tested, (2) correlation of data obtained with test data from other similar units tested, and (3) comparison of data with previous test data on the same equipment (if available).

18-10 Protective Device Testing.

18-10.1 Fuses. There is no way to test the operation of fuses on a system since this type of device destroys itself while performing its protective function. The only test that can be performed on a fuse in the field is a continuity test to determine whether or not the fuse has "blown." A partial operational test may be performed if desired by passing a current through the fuse equal to or slightly less than its rated current to assure that the fuse will carry rated current without operating. If this is done, care should be taken not to exceed the "damage curve" of the fuse as published by the manufacturer.

18-10.2 Low-Voltage Circuit Breakers, General. Low-voltage circuit breakers can generally be divided into two categories depending on the applicable industry design standards:

1. *Molded-Case Circuit Breakers.* Designed, tested, and evaluated in accordance with NEMA AB-1 and Underwriters Laboratories Inc. Standards for Safety, UL 489.

2. *Low-Voltage Power Circuit Breakers.* Designed, tested, and evaluated in accordance with NEMA SG-3 and ANSI C37.13.

18-10.2.1 Field Testing in General. The procedures outlined in Sections 2 and 3 of the above NEMA publication in are intended for checking the condition and basic electrical operation of circuit breakers, but they cannot be considered as calibration tests or comparisons to laboratory tests. Section 3 outlines factors to be considered if laboratory accuracy is to be approached. If checking indicates maloperation, the circuit breaker should be removed and sent to the manufacturer for investigation and test. *It is not advisable to attempt repairs in the field.* If field testing under categories (2) or (3) above is required, then it is recommended that a competent field service team (either in-house or outside contractor) be employed and that instructions be followed as recommended by the above NEMA publication.

18-10.2.2 Assistance. Where needed, manufacturers, electrical contractors, and other competent service organizations will generally provide field-test services; some are equipped to perform field tests on any make unit. Such service will be found more practicable where accurate tests are required, and for all tests on circuit breakers of 600-ampere capacity and above. This is, in part, due to the need for special heavy loading equipment, and also due to the difficulty of making suitable testing connections.

18-10.2.3 Field Testing of Circuit Breakers Employing Solid-State Trips. Breakers employing solid-state trip units offer testing opportunities not readily available in other molded-case or low-voltage power breakers. Since solid-state trip units are designed to operate on low-level currents obtained via the secondaries of current transformers mounted on the phase conductors, small, compact test kits can be utilized in performing field tests with a high degree of accuracy. Since these breakers have unique design characteristics, the manufacturers should be consulted for available test kits and testing instructions. *Attempted field repair of the solid-state trip units should be avoided.* Any suspected malfunction should be referred to a competent service group.

18-10.2.4 Molded-Case Circuit-Breaker Testing.

(a) *Molded-Case Circuit Breakers, General.* Molded-case circuit breakers are available in a wide variety of sizes, shapes, and ratings. Voltage ratings — by standard definitions — are limited to 600 volts although special applications have been made to 1,000 volts. Current ratings are available from 10 through 4,000 amps. Molded-case circuit breakers can be categorized generally by the types of trip units employed as described in Section 11-5. Electrical testing should be performed in a manner and with the type of equipment required by the type of trip unit employed.

(b) *Testing Thermal-Magnetic Circuit Breakers.* The electrical testing of thermal-magnetic circuit breakers can be divided into three steps:

1. Overload of individual poles at 300 percent of trip rating.
2. Verification test procedures.
3. Verification of manufacturer's published data.

Complete and detailed instructions for testing molded case circuit breakers in accordance with the above steps are outlined in detail in the NEMA publication, *Procedures for Verifying Field Inspection and Performance of Molded Case Circuit Breakers.* Individual manufacturers also publish recommended testing procedures as well as time-current characteristic tripping curves.

(c) *Overload Testing Considerations.* When testing circuit-breaker tripping characteristics, *it is recommended that the overcurrent tests be performed on individual poles at 300 percent of rated current.* The reaction of the circuit breaker to this overload is indicative of its reaction throughout its entire overcurrent tripping range. This load is chosen as the test point because it is relatively easy to generate the required current in the field and the wattage per pole from line to load is large enough, so the dissipation of heat in the non-active pole spaces is minor and does not affect the test results appreciably.

(d) *Overcurrent Trip Data.* Table 18-10.2.4(d) outlines the current and trip-time values as recommended by NEMA. The minimum/maximum range of values in Table 18-10.2.4(d) was developed to encompass most brands. For more specific values, refer to the manufacturer's data for the circuit breaker being tested.

(e) *Evaluation of Results.*

1. Minimum trip times (Cols. 3 and 4). Values shown in Table 18-10.2.4(d) should not be considered significant in field testing unless nuisance tripping has been experienced. The values shown are provided as a guideline only. If minimum tripping times are lower than those shown in Table 18-10.2.4(d), the breaker should be retested after being de-energized and cooled for the required time.

2. Maximum trip times (Col. 5). Under normal test conditions, the circuit breaker will trip in less than the maximum values shown in Table 18-10.2.4(d), Column 5. Under improper test conditions the maximum values may exceed those given in Table 18-10.2.4(d).

3. Maximum tripping times for cable protection (Col. 6). If the test value exceeds the maximum tripping time shown in column 5 but falls below the maximum tripping times for cable damage, the circuit breaker is providing an acceptable level of protection. Coordination with

Table 18-10.2.4(d) Values for Molded Case Circuit Breaker Overcurrent Trip Test

(at 300 Percent of Rated Continuous Current of Breaker)

Voltage, Volts	Range of Rated Continuous Current, Amperes	Tripping Time, Seconds: Minimum: Thermal Breakers	Tripping Time, Seconds: Minimum: Magnetic Breakers	Tripping Time, Seconds: Maximum	Tripping Time, Seconds: Maximum Tripping Times for Cable Protection*
(1)	(2)	(3)	(4)	(5)	(6)
240	15-45	3	..	50	100
240	50-100	5	..	70	200
600	15-45	5	5	80	100
600	50-100	5	5	150	200
240	110-225	10	5	200	300
600	110-225	10	..	200	300
600	250-450	25	..	250	300
600	500-600	25	10	250	350
600	700-1200	25	10	450	600
600	1400-2500	25	10	600	750

*These values are based on heat tests conducted by circuit breaker manufacturers on conductors in conduit.

other protective devices should be considered before replacing a circuit breaker that trips beyond the time-current curve.

(f) *Testing Instantaneous-Only Circuit Breakers.* The testing of instantaneous-only circuit breakers requires the use of elaborate constant rate-of-rise test equipment coupled with accurate current-monitoring instrumentation — preferably digital read-out — for accurate confirmation of manufacturers' test results. Unless this type of equipment is available, it is recommended that these breakers be referred to the manufacturer, electrical contractor, or other competent service organization when calibration is required.

18-10.2.5 Molded-Case Circuit-Breaker Testing.

(a) *Overcurrent Trip-Device Testing.* Most low-voltage power circuit breakers are equipped with overcurrent trip devices that sense overload of fault currents and trip the breaker. These devices can be either electromechanical or solid state and will usually have two or more of the following types of elements:

1. Long Time-Delay Element. This element is designed to operate on overloads between its pickup setting and the pickup of a short time delay or an instantaneous element. The electromechanical long time-delay pickup adjustment is generally within the range of 80 to 160 percent of the trip-device rating. Settings higher than an electromechanical trip-device ampere rating do not increase the continuous-current rating of the trip device and in no event is the rating increased beyond the breaker frame size. The operating time of this element ranges from seconds to minutes.

2. Short Time-Delay Element. This element has a time delay measured in cycles and is used to protect against moderate fault currents and short circuits. This element usually may be adjusted to pick up within the range of 250 to 1,000 percent of the trip-device rating.

3. Instantaneous Element. This element has no intentional time delay and is used to protect against heavy fault currents and short circuits. The pickup settings for this type of element usually range from 500 to 1,500 percent of the trip-device rating.

4. Ground-Fault Element. This element is available only on solid-state devices and is used to protect against ground-fault currents at levels below those that would be sensed otherwise.

(b) The testing of electromechanical trip devices or solid-state devices by the primary injection method requires the use of a high current test set capable of producing sufficient current at low voltage to operate each of the elements of the trip device. This test must have means of adjusting the amount of current applied to the trip device and a cycle and second timer to measure the amount of time to trip the breaker at each current setting. At least one test should be made in the range of each element of the trip device. The long time-delay element should ordinarily be tested at approximately 300 percent of its setting. The short time-delay element should be tested at 150 to 200 percent of its setting. The instantaneous element should be tested at 90 and 110 percent of its setting to assure that it does not operate at too low a current level, yet will operate at the proper level. For the test of the instantaneous element, the applied current must be symmetrical without an asymmetrical offset, or random errors will be introduced. As-Found and As-Left tests should always be performed if any need of adjustments is found.

18-10.3 Protective Relays.

18-10.3.1 General.

(a) (*See caution, 6-8.7.1.*) Protective relays are used in conjunction with medium-voltage circuit breakers (above 600 volts) to sense abnormalities and cause the trouble to be isolated with minimum disturbance to the electrical system and with the least damage to the equipment at fault. They have the accuracy and sophistication demanded by the protective requirements of the primary feeder circuits and larger electrical equipment. Protective relays designed to be responsive to an abnormal excursion in current, voltage, frequency, phase-angle, direction of current or power flow, etc., and with varying operation characteristics are commercially available. Each relay application requires custom engineering to satisfy the parameters of its particular intended function in the system.

(b) The more common protective relay is of the electromechanical type. That is, some mechanical element such as an induction-disk, an induction cylinder, or magnetic plunger is caused to move in response to an abnormal change in a parameter of the electrical system. The movement can cause a contact in the control circuit to operate, tripping the related circuit breaker. Protective relays should be acceptance tested prior to being placed in service, and periodically thereafter to ensure reliable performance. In a normal industrial application, periodic testing should be done at least every two years.

(c) The various facets involved in testing protective relays can be listed as follows:

1. The technician must understand the construction, operation, and testing of the particular relay.

2. The manufacturer's instruction bulletin, as identified on the nameplate of the relay, should be available.

3. The technician should be given the settings to be applied to each particular relay, and the test points. This data is often furnished on a time-current curve of the coordination study displaying the characteristics of the relay.

4. A test instrument, suitable to accurately accommodate the various acceptance and periodic maintenance tests described in the manufacturer's instruction manual, should be available.

5. Most protective relays can be isolated for testing while the electrical system is in normal operation. However, an operation of the breaker is required to ascertain that the operation of the relay contacts will trigger the intended reaction, such as to trip the associated circuit breaker.

18-10.3.2 Testing Procedure.

(a) *Inspection.* If required or desirable, each relay should be removed from its case for a thorough inspection and cleaning. If the circuit is in service, remove one relay at a time so as not to totally disable the protection. The areas of inspection are detailed in the manufacturer's instruction manual. These generally consist of inspection for loose screws, friction in moving parts, iron filings between the induction disk and permanent magnet, and any evidence of distress with the relay. The fine silver contacts should be cleaned only with a burnishing tool.

(b) *Settings.* Apply prescribed settings or ascertain that they have been applied to the relay.

(c) *Pickup Test.* In the case of a time-overcurrent relay, its contacts should eventually creep to a closed position with a magnitude of current introduced in its induction coil equal to the tap setting. The pickup is adjusted by means of the restraining spiral-spring adjusting ring. A pickup test on a voltage relay is made in much the same manner.

(d) *Timing Test.* In the case of a time-overcurrent relay, one or more timing tests are made at anywhere from two to ten times tap setting to verify the time-current characteristic of the relay. One timing point should be specified in the prescribed settings. Tests should be made with the relay in its panel and case, and the time test run at the calibration setting.

For example, in the case of one particular overcurrent relay having a 5 ampere tap setting, the timing test could be specified as "25 amperes at 0.4 seconds." It could be seen from the family of curves in the manufacturer's instruction manual for that relay that the test should result in a time dial setting of approximately 1.6.

A timing test should be made on most types of relays.

(e) *Instantaneous Test.* Some protective relays are instantaneous in operation, or may have a separate instantaneous element. In this context, the term instantaneous means "having no intentional time delay." If used, the specified pickup on the instantaneous element should be set by test. Again referring to the relay used in the example above, at two times pickup, its instantaneous element should have an operating time of between 0.016 and 0.030 seconds.

(f) *Test of Target and Seal-In Unit.* Most types of protective relays have a combination target and seal-in unit. The target indicates that the relay has operated. The seal-in unit is adjustable to pickup at either 0.2 or 2.0 amperes. The setting for the seal-in unit must be specified with the relay settings.

It should be verified by test that the contacts will seal in (hold in closed position) with the minimum specified dc current applied in the seal-in unit.

(g) *Test of Tripping Circuit.* A test should be made, preferably at time of testing the relays, to verify that operation of the relay contacts will cause the breaker to trip.

18-11 Transformer Turns Ratio and Polarity Tests.

18-11.1 The turns ratio test is used to determine the number of turns in one winding of a transformer in relation to the number of turns in the other windings of the same phase of the transformer. The polarity test determines the vectoral relationships of the various transformer windings. The turns ratio test is used as both an acceptance and a maintenance test, while the polarity test is primarily an acceptance test.

18-11.2 The tests are applicable to all power, distribution, and instrument transformers. The test equipment used will ordinarily be a turns ratio test set designed for the purpose, although, if not available, two voltmeters or two ammeters (for current transformers only) may be used. If the two meter method is used, the instruments should be at least of the 0.25 percent full-scale accuracy type.

18-11.3 When a turns ratio test is performed, the ratio should be determined for all no-load taps. If the transformer is equipped with a load-tap changer, the ratio should be determined for each LTC position. If the transformer has both an LTC and a no-load tap changer, then the ratio should be determined for each position of the LTC to one position of the no-load tap changer and vice-versa.

This test is useful in determining whether a transformer has any shorted turns or improper connections and; on acceptance testing, to verify nameplate information.

18-12 Contact Resistance Testing. This test is used to test the quality of the contacts on switches and circuit breakers. A test set designed for this purpose is available with direct scale calibration in microhms, capable of reading contact resistances of 10 microhms or less. An alternate method is to pass a known level of dc current through the contact structure and to measure the dc millivolt drop across the contacts. The data obtained may then be converted to resistance by applying Ohm's Law. When millivolt drop data is used directly to describe contact resistance, it is normally stated in terms of the continuous current rating of the device. Millivolt drop data obtained at currents lower than the rated continuous current rating may be converted to the continuous current rating basis by multiplying the actual millivolt readings by the ratio of the continuous rated current to the actual test current. The alternate method requires a source of at least 100 amperes with a millivolt meter of approximately 0-20 millivolt range.

The contact resistance should be kept as low as possible to reduce power losses at the contacts with the resultant localized heating, which will shorten the life of both the contacts and nearby insulation.

18-13 Equipment Ground Impedance Testing.

18-13.1 This test is used to determine the integrity of the grounding path from the point of test back to the source panel or supply transformer. A low-impedance grounding path is necessary to facilitate operation of the overcurrent device under ground-fault conditions as well as provide a zero voltage reference for reliable operation of computers and other microprocessor-based electronic equipment.

18-13.2 Instruments are available to measure the impedance of the grounding path. When using these instruments, one should remember that, although a high impedance value is an indication of a problem, for example a loose connection or excessive conductor length, a low impedance readout does not necessarily indicate the adequacy of the grounding path. A grounding path that is found to have a low impedance by the use of relatively low test currents may not have sufficient capacity to handle large ground faults. Visual examinations and actual checking for tightness of connections are still needed to determine the adequacy of the grounding path.

18-13.3 Impedance tests can be performed reliably on circuits where an equipment grounding conductor is not connected to other parallel paths. These may include nonmetallic sheathed cable, circuits installed in nonmetallic conduits and fittings, flexible cords and circuits where an isolated equipment grounding conductor is installed to reduce electrical noise on the grounding circuit.

18-13.4 Ground loop or grounding conductor impedance cannot be measured reliably in situations where metallic conduits are used or where metallic boxes or equipment are attached to metal building frames or interconnected structures. Such situations create parallel paths for test currents that make it impossible to measure the impedance of the grounding conductor, or even to detect an open or missing grounding conductor. Also, the impedance of a steel raceway varies somewhat unpredictably with the amount of current flowing through it. The relatively small test currents used during testing usually produce a higher impedance than actually encountered by fault currents. However, this tends to render the tests conservative and the impedance values may still be acceptable.

18-14 Grounded Conductor (Neutral) Impedance Testing. On solidly grounded low-voltage systems (600 volts or less) supplying microprocessor-based electronic equipment with switching power supplies, this test is used to determine the quality of the grounded conductor (neutral) from the point of test back to the source panel or supply transformer. These electronic loads may create harmonic currents in the neutral that can exceed the current in the phase conductors. A low impedance neutral is necessary to minimize neutral-to-ground potentials and common mode noise produced by these harmonic currents.

Some instruments used to perform the equipment ground-impedance tests in Section 18-13 may be used to perform grounded conductor (neutral) impedance tests.

18-14.1 Grounding Electrode Resistance Testing. Grounding electrode resistance testing is used to determine the effectiveness and integrity of the grounding system. An adequate grounding system is necessary to (1) provide a discharge path for lightning, (2) prevent induced voltages caused by surges on power lines from damaging equipment connected to the power line, and (3) maintain a reference point of potential for instrumentation safety. Periodic testing is necessary because variations in soil resistivity are caused by changes in soil temperature, soil moisture, conductive salts in the soil, and corrosion of the ground connectors. The test set used will ordinarily be a ground resistance test set, designed for the purpose, using the principle of the fall of potential of ac circulated current from a test spot to the ground connection under test. This instrument is direct reading and calibrated in ohms of ground resistance.

18-15 Circuit Breaker Time-Travel Analysis.

18-15.1 This test, used on medium- and high-voltage circuit breakers, provides information as to whether the operating mechanism of the circuit breaker is operating properly. All test instruments should be used in strict compliance with the manufacturer's instructions and recommendations. Failure to do so can result in injury to personnel making the tests as well as producing meaningless data. It presents in graphical form the position of the breaker contacts versus time. This test can be used to determine the opening and closing speeds of the breaker, the interval time for closing and tripping, and the contact bounce. The test provides information that can be used to detect problems such as weak accelerating springs, defective shock absorbers, dashpots, buffers, and closing mechanisms.

18-15.2 The test is performed by a mechanical device which is attached to the breaker. There are several types of devices available to perform this function. One device, a rotating drum with a chart attached, is temporarily connected to the chassis or tank of the breaker. A movable rod with a marking device attached is installed on the lift rod portion of the breaker. As the breaker is opened or closed, the marking device indicates the amount of contact travel on the chart as the drum rotates at a known speed. With another available device, a transducer is attached to the movable rod, and the breaker operation is recorded on an oscillograph.

18-16 Infrared Inspection.

18-16.1 General. The term "infrared inspection," as used in this recommended practice, refers to a procedure of deriving approximate temperature measurements of electrical equipment or materials while they are in service and energized, by remote sensors of infrared radiation.

Infrared inspections of electrical systems are beneficial to reduce the number of costly and catastrophic equipment failures and unscheduled plant shutdowns. Such infrared inspections performed by qualified and trained personnel have uncovered a multitude of potentially dangerous situations. Proper diagnosis and remedial action of these situations have also helped to prevent numerous major losses.

The instruments most suitable for infrared inspections are of the type that use a scanning technique to produce an image of the equipment being inspected. These devices display a picture where the "hot spots" appear as bright or brighter spots.

Infrared surveys can be accomplished by either in-house teams or by the services of a qualified outside contractor. The economics and effectiveness of the two alternatives should be carefully weighed. Many organizations are finding it preferable to obtain these surveys from qualified outside contractors. Because of their more extensive experience, their findings and recommendations are likely to be more accurate, practical and economical than those of a part-time in-house team.

Infrared surveys of electrical systems should not be viewed as a replacement for visual inspections. Visual inspections or checks are still required on lightly loaded circuits or circuits not energized or not carrying current at the time of the infrared survey (e.g., neutral connections).

18-16.2 Advantages of Infrared Inspections. Infrared inspections are advantageous to use in situations where electrical equipment cannot be de-energized and taken out of service or where plant production is affected. They can reduce typical visual examinations and tedious manual inspections and are especially effective in long-range detection situations.

Infrared detection may be accurate, reliable, and expedient to use in a variety of electrical installations. More important, it may be relatively inexpensive to use considering the savings often realized by preventing equipment damage and business interruptions.

Infrared inspections are considered a useful tool to evaluate previous repair work and proof test new electrical installations and new equipment still under warranty.

Regularly scheduled infrared inspections will often require the readjustment of electrical maintenance priorities as well as detect trends in equipment performance that require periodic observation.

18-16.3 Disadvantages. There are some disadvantages to individual ownership of certain types of equipment. Scanning-type thermal imaging devices can be costly to purchase outright. Training is necessary for persons who operate scanning-type thermal imaging instruments.

Infrared inspections require special measures and analysis. Equipment enclosed for safety or reliability may be difficult to scan or to detect radiation from within. Special precautions, including the removal of access panels, may be necessary for satisfactory measurements. Weather may be a factor in the conduct of a survey of electrical systems located outdoors, e.g., overhead electric open lines and substations. Rain may produce abnormal cooling of defective conductors and components, and the reflection of sun rays from bright surfaces may be misread as hot spots. For this reason, infrared work on outdoor equipment may have to be performed at night. This, in turn, presents a problem because electrical loads are usually lower at night and, consequently, the faulty connections and equipment may not overheat enough to enable detection.

The handling of liquid nitrogen, argon, and other liquified gases with their inherent hazards is a disadvantage of some infrared testing equipment.

18-16.4 Desirable Operational Features. The equipment display should be large and provide good resolution of hot spots. The equipment should provide color or black and white photographs to identify the exact location of the "hot spot." The unit should be portable, easy to adjust, and approved for use in the atmosphere in which it is to be used. It should also have a cone of vision that will give enough detail to accurately identify the "hot spot."

The unit should be so designed that the operator knows the degree of accuracy in the display. There should be easily operated checks to verify the accuracy of the display.

18-16.5 Inspection Frequency and Procedures. Routine infrared inspections of electrical systems should be performed annually. Where warranted by loss experience; installation of new electrical equipment; environmental, operational, or load change conditions, more frequent infrared inspections, e.g., quarterly or semiannually, should be performed.

All critical electrical equipment as determined by Section 4-3, Identification of Critical Equipment, should be included in the infrared inspection.

Infrared surveys should be performed during periods of maximum possible loading but not less than 40 percent of rated load of the electrical equipment being inspected.

Infrared surveys should be documented as outlined in 4-5.2, Forms, and Section 18-8, Use of Forms. The electrical supervisor should be immediately notified of critical, impending faults so that corrective action can be taken before a failure occurs. Priorities should be established to correct other deficiencies.

18-17 Fault-Gas Analysis. The analysis of the percentage of combustible gases present in the nitrogen cap of sealed, pressurized oil-filled transformers can provide information as to the likelihood of incipient faults in the transformer. When arcing or excessive heating occurs below the top surface of the oil, some oil decomposes. Some of the products of the decomposition are combustible gases that rise to the top of the oil and mix with the nitrogen above the oil.

The test set for this test is designed for the purpose. A small sample of nitrogen is removed from the transformer and analyzed. The set has a direct reading scale calibrated in percent of combustible gas. Ordinarily, the nitrogen cap in a transformer will have less than one-half percent combustible content. As a problem develops over a period of time, the combustible content can rise to ten or fifteen percent.

A suggested evaluation of the test results is as follows:

PERCENTAGE OF COMBUSTIBLE GAS	EVALUATION
0.0 to 1.0	No reason for concern. Make tests at regularly scheduled intervals.
1.0 to 2.0	Indication of contamination or slight incipient fault. Make more frequent readings and watch trend.
2.0 to 5.0	Begin more frequent readings immediately. Prepare to investigate cause by internal inspection.
Over 5.0	Remove transformer from service and make internal inspection.

18-18 Insulating-Liquid Analysis. Regular tests, on a semiannual basis, should be made on insulating oils and askarels. Samples should be taken from the equipment in accordance with ASTM Method D923-70. The maintenance tests most commonly performed on used insulating liquids, together with the appropriate ASTM test methods, are shown in Table 18-18. Also included in this table are suggested limits to be used to determine whether the liquid is in need of reconditioning or reclamation. For comparison, typical test values for new oil are also included in the table.

Table 18-18 Summary of Maintenance Tests for Insulating Liquids

Test For:	ASTM Method of Test	Test Limits for Maintenance	Typical New Liquid Value
Acidity, Approximate	D1534-64 or D1902-64	Same as Neutralization Number	Below
Color, ASTM	D1500-64 (1968) (Petroleum Oils) (Use also for maintenance testing of Askarel.)	4.0 Max. (oil) 2.0 Max. (Askarel)	1.0 Max. (Oil and Askarel)
Dielectric Breakdown Voltage	D877-67 (Disk Electrodes) or D1816-67 (VDE Electrodes)	22 kV Min. (Oil) 25 kV Min. (Askarel)	26 kV (Oil) 30 kV (Askarel)
Examination, Visual, Field	D1524-69 (Petroleum Oils) or D1702-65 (Askarel)	Cloudy, dirty, or visible water	Clear
Interfacial Tension (Oil Only)	D971-50 (1968) (Ring Method) or D2285-68 (Drop Weight)	18 Dynes/Cm. Min.	35 Dynes/Cm. Min.
Neutralization Number	D974-54 (1968) or D664-58	0.40 Max. (Oil) *(Askarel)	0.04 Max. (Oil) 0.014 Max. (Askarel)
Power Factor	D924-65 (1969)	1.8% Max. (Oil) .5-2.0% (Askarel)	0.1% Max. (25°C)(Oil) .2-.5% Max. (25°C)(Askarel)

*Replace for any value greater than 0.014

18-19 Rotating Machine Testing.

18-19.1 Insulation Resistance Testing.

18-19.1.1 This testing procedure applies to armature and rotating or stationary field windings. A hand crank, rectifier, or battery-operated instrument is suitable for testing equipment rated to 600 volts. For equipment rated over 600 volts, a 1000-volt or 2500-volt motor-driven or rectifier-operated instrument is recommended for optimum test results. Operating machines should be tested immediately following shutdown when the windings are hot and dry. On large machines, the temperature should be recorded and converted to a base temperature in accordance with IEEE 43 to provide continuity for comparative purposes. Always disconnect all voltage sources, lightning arresters, and capacitors or other potential low insulation sources before making insulation measurements. Lead-in cables or buses and line side of circuit breakers or starters can be tested as a part of the circuit provided a satisfactory reading is obtained. If the insulation resistance is below the established minimum, the circuit components should be tested separately until the low insulation reading is located. Insulation resistance history based on tests conducted on new motors or after rewind, cleaning, or from recorded data made under uniform conditions form a very useful basis for interpretation of a machine winding condition. When comparing records of periodic tests *any persistent downward trend is an indication of insulation trouble* even though the values may be higher than the recommended minimum safe values listed below.

18-19.1.2 Insulation resistance readings taken for purposes of correlation should be made at the end of a definite interval following the application of a definite test voltage. For purposes of standardization, 60-second applications are recommended where short time single readings are to be made on windings and where comparisons with earlier and later data are to be made. Recommended minimum acceptable insulation values without further investigation are as follows:

Rotating Machinery Voltage	Insulation Resistance
1000 volts and below	2 megohms
Above 1000 volts	1 megohm per 100 volts plus 1 megohm

18-19.2 Dielectric Absorption Testing. A more complete and preferred test applies the voltage for ten minutes or more to develop the dielectric absorption characteristic. The curve obtained by plotting insulation resistance against time gives a good indication of moist or dirty windings. A steady rising curve is indicative of a clean, dry winding. A quickly flattening curve is the result of leakage current through or over the surface of the winding and is indicative of a moist or dirty winding. If facilities are not available for a ten-minute test, readings may be taken at 30 and 60 seconds. The ratio of the 60 to 30 second or the 10 to 1 minute ratio will serve as an indication of the winding condition. The following table should serve as a guide in interpreting these ratios.

CONDITION	60:30 SECOND RATIO	10:1 MINUTE RATIO
Dangerous	—	Less than 1
Poor	Less than 1.1	Less than 1.5
Questionable	1.1 to 1.25	1.5 to 2
Fair	1.25 to 1.4	2 to 3
Good	1.4 to 1.6	3 to 4
Excellent	Above 1.6	Above 4

18-19.3 Over-potential Testing.

18-19.3.1 Overvoltage tests are performed during normal maintenance operations or after servicing or repair of important machines. Such tests, made on all or parts of the circuit to ground, ensure that the insulation level is sufficiently high for continued safe operation. Both ac and dc test equipment are available. There is no conclusive evidence that one method is preferred over the other. However, where equipment using several insulating materials is tested, ac stresses the insulation more nearly to actual operating conditions than dc. Also, more comparable data have been accumulated since ac testing has had a head start. However, the use of dc has several advantages and is rapidly gaining favor with increased usage. The test equipment is much smaller, lighter in weight, and lower in price. There is far less possibility of damage to equipment under test and dc tests will give more information than is obtainable with ac testing.

18-19.3.2 The test overvoltages that should be applied will depend on the type of machine involved and level of reliability required from the machines. However, it should be of sufficient magnitude to search out weaknesses in the insulation that might cause failure. Standard over-potential test voltage when new is twice rated voltage plus 1000 volts ac. On older or repaired apparatus, tests are reduced to approximately 50 to 60 percent of the factory (new) test voltage. (*See IEEE 4.*) For dc tests, the ac test voltage is multiplied by a factor (1.7) to represent the ratio between the direct test voltage and alternating rms voltage. (*See IEEE 95.*)

18-19.3.3 A high-potential test made to determine the condition of the insulation up to a predetermined voltage level is difficult to interpret. It is common practice to compare known good results against test specimens to determine what is acceptable and what fails the test. For a dc high-potential test, the shape of the leakage current plotted against voltage rise is an additional used criteria.

As long as the knee of the curve (which indicates impending breakdown; point c in Figure 18-19.3.3) does not occur below the maximum required test voltage, and as long as the shape of the curve is not too steep compared with that of similar equipment or prior test of the same equipment, the results may be considered satisfactory. It should be recognized that if the windings are clean and dry, overvoltage tests will not detect any defects in the end turns or in lead-in wire located away from the stator iron.

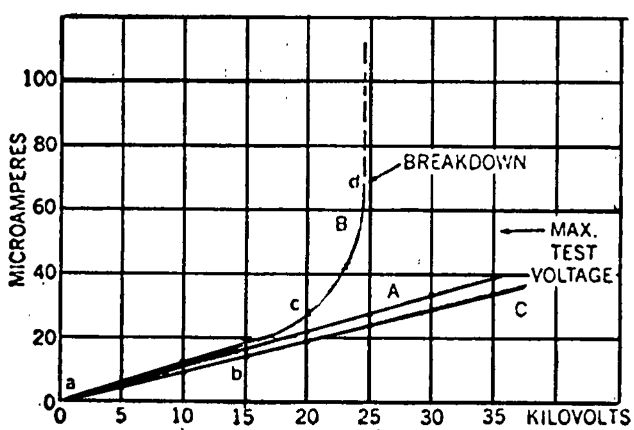

Figure 18-19.3.3

18-19.4 Surge Comparison Testing.

18-19.4.1 Surge comparison testing can detect turn-to-turn, coil-to-coil, group-to-group, and phase-to-phase winding flaws that cannot be detected by insulation resistance, dielectric absorption, or over-potential testing. Surge testing should not be undertaken until after the integrity of insulation to ground has been verified.

18-19.4.2 The surge testing principle is based on the premise that the impedances of all three-phase windings of a three-phase machine should be identical if there are no winding flaws. Each phase (A/B, B/C, C/A) is tested against the others to determine if there is a discrepancy in winding impedances.

18-19.4.3 The test instrument imposes identical, high voltage, high frequency pulses across two phases of the machine. The reflected decay voltages of the two windings are displayed and captured on an oscilloscope screen. If the winding impedances are identical, the reflected decay voltage signatures will coincide and appear on the screen as a single trace. Two dissimilar traces indicate dissimilar impedances and a possible winding flaw.

18-19.4.4 The testing and interpretation of results should be conducted by a trained individual.

18-19.5 Other Tests. There are several other types of tests, depending on the need and desired results. These are listed below; however, these more complex tests are not employed unless apparatus performance indicates these tests must be made, and experienced testers are available with the test equipment.

Turn-to-Turn Insulation

Slot Discharge and Corona

Winding Impedance Test

Power Factor Value

Core Loss Test

18-20 Three-Phase 4-Wire Neutral Current Testing.

18-20.1 Situations exist where it is possible for the neutral current of three-phase systems to exceed the ampacity of the neutral conductor in normal operation. This is usually due to unbalanced phase loading, nonsinusoidal load currents (harmonics), or a combination of the two.

There are certain conditions where even perfectly balanced loads result in significant neutral currents. Nonlinear loads, such as rectifiers, computers, variable speed drives, electrical discharge lighting fixtures and switching mode power supplies, cause phase currents that are not sinusoidal.

18-20.2 Symptoms of this condition might be overheating of the neutral conductor, deterioration of conductor insulation, carbonized insulation, and measurable voltage

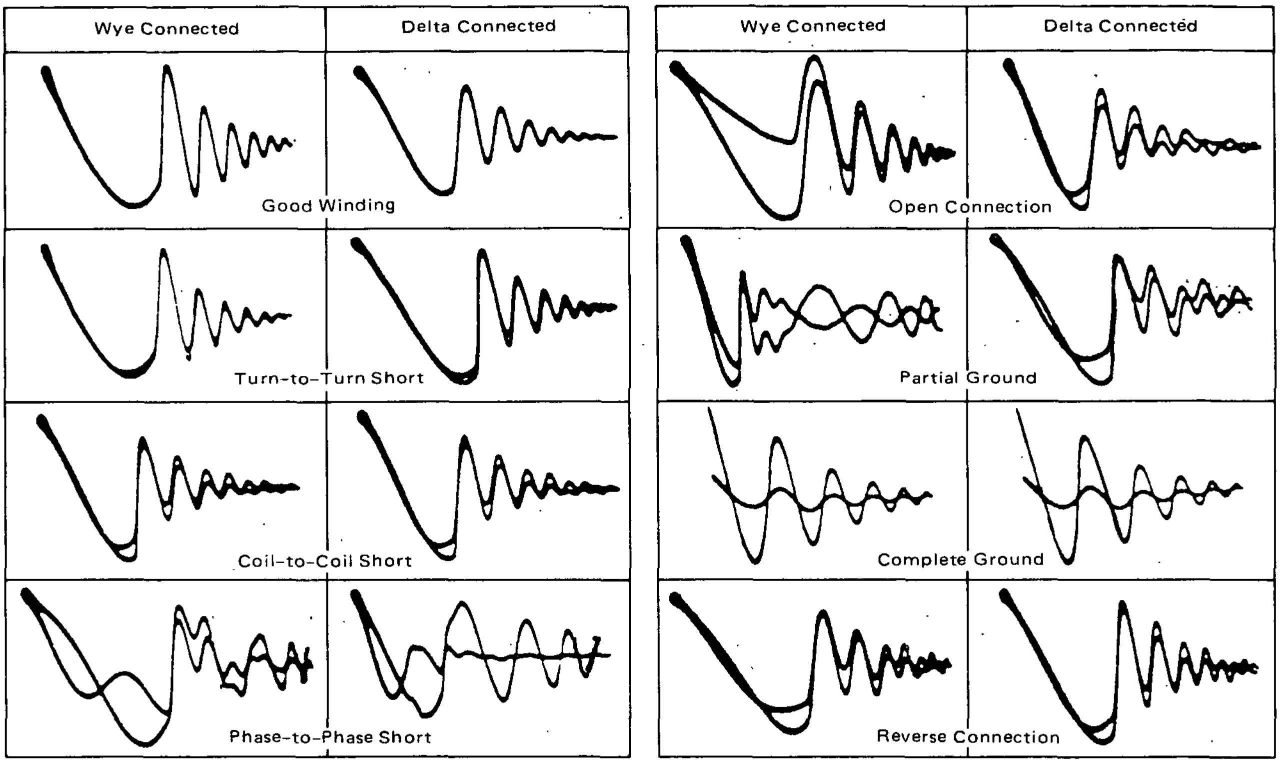

Figure 18-19.4.3 Waveshapes for Winding Faults

between the neutral and ground conductors (common mode noise). This condition can cause a fire or malfunction of microprocessor based equipment.

18-20.3 The problem may be detected using a true RMS ammeter to measure the current flowing in the neutral conductor. The use of an average responding ammeter calibrated to read the RMS value of a sine wave should not be used as it will not yield valid results when used on nonsinusoidal waveforms. If the neutral current is found to be excessive, the current in each phase should be measured to determine if an abnormal condition exists. If excessive neutral current exists and the phase currents are not excessive, harmonic content is the most likely cause. A means of analyzing neutral current containing harmonic components is through the use of a wave or spectrum analyzer. Most analyzers on the market today have the ability to provide a direct readout of the harmonic's magnitude.

18-20.4 Verify that the neutral is bonded to the grounding electrode conductor only at the service and at each separately derived source, where used.

Chapter 19 Maintenance of Electrical Equipment Subject to Long Intervals Between Shutdowns

19-1 General.

19-1.1 Due to the more extensive and costly damage possible from electrical failures in continuous-process operations, plus the longer intervals between shutdowns, more thorough and comprehensive maintenance procedures are recommended. The need for and frequency of inspection and maintenance is determined by the effect on safety, plant operation, and severity of service.

The primary effects of electrical failure or malfunction are those directly associated with the failure, and usually involve the damage to electrical equipment. The secondary effects are those associated with the process or product. Damages resulting from secondary effects can be much more extensive and in some cases, catastrophic.

19-1.2 In addition to more intensive maintenance procedures, this chapter will cover system design considerations in so far as they relate to safety and maintainability as well as first and future costs.

19-2 Electrical Distribution.

19-2.1 General Aspects of Maintaining Medium- and Low-Voltage Systems.

19-2.1.1 Unless an electrical distribution system is adequately engineered, designed, and constructed, it will not provide reliable service, no matter how good the maintenance program. Therefore, the following requirements are much more essential for electrical distribution systems that supply production equipment that must operate for long periods between shutdowns.

(a) Careful planning in the engineering and design stages to permit maintenance work without load interruptions. Alternate electrical equipment and circuits should be provided to permit routine or emergency maintenance on one while the other supplies the load that cannot be shut down. For instance, automatic or manual transfer equipment will permit the load to be switched, with minimal interruption, from a source of circuit that fails to one that is operating.

(b) High-quality equipment that has sufficient capacity and features that permit reasonable inspection of the energized parts while in operation without hazard to an inspector using proper precautions. Viewing windows or expanded metal guards inside hinged doors provide a safe means for inspecting energized components inside enclosures. Complete barriers between adjacent switch and breaker sections, etc., will permit personnel to work safely inside a de-energized compartment while adjacent ones are energized.

Close inspection of the equipment before shipment is the best way to certify compliance with specifications.

(c) Strict adherence to construction specifications complete with detailed drawings and installation procedures.

(d) Close scrutiny during all phases of construction. This is essential to ensure adequate quality workmanship and that cables, insulating materials, and other components are not damaged by poor practices.

(e) Acceptance testing (in accordance with applicable recognized standards) including functional testing and inspection. These are valuable to detect equipment that is defective, badly damaged, or installed in an inferior manner. In addition, reinspection and retesting within one or two years after energization may reveal conditions that can lead to in-service failures.

19-2.1.2 After these prerequisites are satisfied, an adequate EPM program will help to keep the system in good condition and provide the necessary reliability over a long period.

19-2.1.3 Maintenance, inspection, and test methods for equipment that must operate for long periods are essentially the same as for equipment that may be shut down frequently. However, the required work must be performed with more care and diligence to obtain the desired reliability for service to loads that must operate continuously for months or years.

19-2.1.4 The following is necessary to effect an adequate EPM program for reliable long-term operation of an electrical power system:

(a) Good knowledge of the entire power system by all associated personnel. Posted or readily available diagrams, procedures, and precautions are highly beneficial aids in keeping personnel knowledge up to date.

(b) General understanding of the loads served and their electrical quality and continuity of service requirements.

(c) Length of time between scheduled maintenance shutdowns for utilization equipment, process changes, etc., that will influence the length of intervals between electrical power system maintenance shutdowns.

(d) A complete list of all the electrical system equipment associated with a given process or manufacturing system to assure that all of it is maintained during one shutdown instead of doing it piecemeal which would require additional shutdowns.

(e) The amount of time during the utilization equipment shutdown when the electrical power system can be de-energized for EPM.

(f) Knowledge of electrical power system components, including operating and maintenance data. This information is often included in the manufacturers' maintenance instructions.

(g) Knowledge of ambient conditions, such as heat, moisture, and vibration, that may affect the equipment.

(h) Ability to recognize abnormal conditions and early evidence of potential problems, such as overheating and surface tracking on insulating materials, that can cause failure if not corrected in sufficient time.

(i) Standardized maintenance procedures shown in other portions of the text modified by the above information and knowledge gained through experience.

(j) Knowledge of services available from local, area, and national electrical maintenance contractors that have specialized test equipment and highly qualified personnel who routinely perform this work. Some of the items that fall into this category are: relay calibration and testing; circuit breaker overcurrent trip-device calibration and testing; high-potential testing; power-factor testing; insulating liquid testing and reconditioning; switchgear maintenance and testing; and maintenance and testing of solid-state devices.

Unless the amount of specialized work is sufficient to keep plant electrical maintenance personnel adept in the performance of such work, the use of specialized electrical maintenance contractors should be considered. However, plant maintenance supervision must have sufficient electrical knowledge to decide with the contractor on the required work to be done and to closely follow his performance to assure full compliance. Merely telling a contractor to maintain or test the equipment usually creates a false sense of security that can be shattered by a serious failure caused by inadequate or incorrect maintenance procedures. The result is often the same when plant supervision does not sufficiently instruct plant maintenance personnel.

19-2.1.5 When a piece of equipment or component fails, merely making repairs or replacement is not sufficient. A complete analysis should be made to determine the cause and formulate corrective action to prevent recurrence in the same and similar equipment.

Following is a list of equipment for which maintenance, inspection, and testing guide tables are located in the appendices. The material contained therein is of a general nature and may have to be revised to conform more closely to the equipment being maintained to assure the coverage necessary for the required reliability. Experience has indicated that the frequencies of maintenance, etc., shown in the tables is sufficient for most installations. They might have to be tailored to suit installations where the ambient conditions are more or less severe.

(a) Medium-Voltage Equipment (Over 1,000 V).

1. Cables, Terminations, and Connections.
2. Liquid-filled Transformers.
3. Dry-type Transformers.
4. Metal-clad Switchgear.
5. Circuit Breakers.
6. Metal-enclosed Switches.
7. Bus Ducts.
8. Protective Relays.
9. Automatic Transfer Control Equipment.
10. Fuses.
11. Lightning Arresters.

(b) Medium- and Low-Voltage Equipment.

1. Overhead Lines.

(c) Low-Voltage Equipment (Below 1,000 V).

1. Cables and Connections.
2. Dry-type Transformers.
3. Switchgear.
4. Drawout-type Circuit Breakers.
5. Buses and Bus Ducts.
6. Panelboards.
7. Protective Relays.
8. Automatic Transfer Control Equipment.
9. Circuit Breaker Overcurrent Trip Devices.
10. Fuses.
11. Lightning Arresters.

19-3 Utilization.

19-3.1 General.

19-3.1.1 The utilization of electrical energy in industry is the conversion of electrical energy into useful work such as mechanical operations, lightning, and heating. Of primary concern is the maintenance of the many kinds of utilization equipment used with processes that operate for long intervals between shutdowns. Utilization equipment as covered here is considered to operate at 480 volts and less.

19-3.1.2 Chapters 4 and 5 make reference to the need for planning and developing an EPM program and describe some of the fundamentals. Utilization equipment that serves equipment that operates for long intervals between shutdowns should receive special consideration. The serviceability and safety of the equipment should be thoroughly studied. During the initial design stages, thought needs to be given to EPM with ease of maintenance and accessibility being of extreme importance in the design considerations, with emphasis on access for adequate visual and infrared inspection of all busbars and joints.

19-3.1.3 Maintenance personnel who are going to service the equipment should be consulted during the design phases.

19-3.2 Records and Inspection Tours.

19-3.2.1 Keeping records on utilization equipment that operates over long intervals is more important than short-interval equipment. Wiring changes, parts replacement, and other modifications should all be accurately recorded.

19-3.2.2 Schedules should be laid out for periodic inspection tours of utilization equipment. Records of findings on these inspection tours will help to indicate trends. Another important reason for good recordkeeping is that personnel often change and it is necessary for those presently involved to know what has been done prior to their involvement.

19-3.2.3 Power and lighting panel directories must be kept up to date and be accurate.

19-3.3 Power Distribution Panels.

19-3.3.1 Power distribution panels can either be fuse- or circuit breaker-type panels. Where critical circuits are involved, they should be appropriately identified by tags, labels, or color coding.

19-3.3.2 Seldom are power panels de-energized, and then only for circuit changes; it is at this time EPM can be scheduled. Although procedures can be developed for working on them live, it is not recommended because of the safety hazards involved. There is always the possibility of an error or accidental tripping of a main breaker causing an unscheduled shutdown. During operating periods, the panels can only be checked for hot spots or excessive heat. This should be done at a reasonable interval in accordance with the importance of the circuit. A record should be made of areas that have given trouble; do not rely on memory.

19-3.3.3 During a shutdown and while the panel is dead, all bolted connections should be checked for tightness, and visually inspected for discoloration. Should there be discoloration, further investigation should be made and possibly the parts affected, replaced. For further information, refer to Chapters 11 and 13.

19-3.4 Lighting Panels.

19-3.4.1 Lighting panels generally have the same problems as power panels. However, experience indicates a higher probability of circuit overloading and thus protective device overheating. Since such panels applied in long-term maintenance areas usually feed important circuits, overheating problems should be corrected immediately.

19-3.5 Plug-in-type Bus Duct.

19-3.5.1 Since plug-in bus duct is seldom used in long-term areas, maintenance of this equipment will not be covered here. Refer to Chapters 9, 11, and 13 for related information.

19-3.6 Wiring to Utilization Equipment.

19-3.6.1 Maintenance procedures outlined in Chapter 8 are recommended. The visual inspection interval should be based on the importance of the circuits and previous experience. In addition, more extensive insulation testing may be warranted during shutdown periods to ensure higher reliability.

19-3.7 Rotating Equipment.

19-3.7.1 Proper maintenance of electric motors and rotating equipment is essential to prevent unscheduled downtime. Their most trouble-prone parts are bearings. The quantity of lubricant, the frequency of lubrication, the method of application, and the type of lubricant are of prime concern. Although lubrication of rotating equipment is discussed in Chapter 14, it is important enough with equipment that operates for long periods between shutdowns, and especially motors, that further mention is made here. Suggestions for both oil and grease lubrication systems are listed below.

19-3.7.2 Grease Lubrication Systems. Grease is the most common lubricant used for electric motor bearings. It provides a good seal against the entrance of dirt into the bearing, has good stability, is easy to apply, and is easy to contain without elaborate seals. For extended service intervals, an extremely stable grease is required. Grease should be selected on the basis of the expected temperature range of service. The motor manufacturer can provide advice on exactly which grease to use. A grease that is compatible with the grease already in the bearing should be used.

19-3.7.3 Regreasing. The correct quantity of lubricant in a rolling contact bearing is vital to its proper operation. Either insufficient or excessive lubrication will result in failure. Excessive lubrication may cause motor failure due to migration of grease into the motor winding. Table 19-3.7.3 will serve as a guide in determining regreasing intervals by the type, size, and service of the motor to obtain the most efficient operation and the longest bearing life. Where a variety of motor sizes, speeds, and types of service are involved in a single plant, a uniform relubrication period is sometimes selected. A yearly basis is common, for instance, and such a yearly regreasing might conveniently be carried out on a plantwide basis during a vacation shutdown.

Motors equipped with grease fittings and relief plugs should be relubricated by the following procedure using a low-pressure grease gun:

(a) Wipe clean the pressure-gun fitting and the regions around the motor grease fittings.

(b) Remove the relief plug and free the relief hole of any hardened grease.

(c) Add grease with the motor at standstill until new grease is expelled through the relief hole. In a great majority of cases it is not necessary to stop the motor during relubrication, but regreasing at standstill will minimize the possibility for grease leakage along the shaft seals.

(d) Run the motor for about 10 minutes with the relief plug removed to expel excess grease.

(e) Clean and replace the relief plug.

Table 19-3.7.3 Guide for Maximum Regreasing Periods

Type of Service	Motor hp Up to 7½	10-40	50-150	Over 150
Easy: infrequent operation (1 hr per day), valves, door openers, portable floor sanders	10 yr	7 yr	4 yr	1 yr
Standard: 1- or 2-shift operation, machine tools, air-conditioning apparatus, conveyors, garage compressors, refrigeration apparatus, laundry machinery, textile machinery, wood-working machines, water pumping	7 yr	4 yr	1½ yr	6 mo
Severe: motors, fans, pumps, motor generator sets, running 24 hr per day, 365 days per year; coal and mining machinery; motors subject to severe vibration; steel-mill service	4 yr	1½ yr	9 mo	3 mo
Very severe: dirty, vibrating applications, where end of shaft is hot (pumps and fans), high ambient	9 mo	4 mo	3 mo	2 mo

19-3.7.4 For totally enclosed, fan-cooled motors, the above instructions apply for greasing the drive-end bearing. The fan-end housing is frequently equipped with a removable grease relief pipe that extends to the outside of the fan casing. First remove, clean, and replace the pipe. Next, during the addition of new grease from a grease gun, remove the relief pipe several times until grease is observed in the pipe. After grease is once observed to have been pushed out into this pipe, no more should be added. The pipe, after again being cleaned and replaced, will then act as a sump to catch excess grease when expansion takes place during subsequent operation of the motor.

In many vertical motors, the ball-bearing housing itself is relatively inaccessible. In such cases, a grease relief pipe is frequently used in a manner similar to that in the totally enclosed, fan-cooled motors. The same regreasing procedures should be used as described above for the TEFC motors.

Motors with sealed bearings cannot be relubricated.

19-3.7.5 In many small motors, no grease fittings are used. Such motors should be relubricated by removing the end shields, cleaning the grease cavity, and refilling three-quarters of the circumference of the cavity with the proper grade of grease. In the end shields of some small motors, threaded plugs are provided that are replaceable with grease fittings for regreasing without disassembly.

Since regreasing of motor bearings tends to purge the old grease, a more extensive removal of all the used grease is seldom necessary. Whenever a motor is disassembled for general cleaning, however, the bearings and housing should be cleaned by washing with a grease-dissolving solvent. To minimize the chance of damaging the bearings, they should not normally be removed from their shaft for such a washing. After thorough drying, each bearing and its housing cavity should be filled approximately one-half to three-fourths full with new grease before reassembly. Avoid spinning the bearing with an air hose during cleaning, and do not reuse any bearing that has been removed from the shaft by pulling on the outer ring.

19-3.7.6 Oil Lubrication Systems. Oil lubrication is necessary when a motor is equipped with sleeve bearings. It is sometimes used for roller contact bearings under certain conditions.

Oils for lubricating electrical motors should be high-quality circulating oils with rust and oxidation inhibitors.

The oil viscosity required for optimum operation of motor bearings is determined by the motor speed and the operating temperature.

In general, 150 S.U.S. oil is used for motor speeds above 1500 rpm, and 300 S.U.S. oil is used for motor speeds below 1500 rpm. These recommendations may vary with specific application and, in particular, with the ambient temperature to which the motor or generator is exposed, and accordingly the user should refer to and follow the motor manufacturer's recommendations relative to oil viscosity.

19-3.7.7 Methods and Quantity.

(a) *Wick Oiling.* Fractional horsepower motors which can be relubricated generally use felt, waste, or yarn packing to feed sleeve bearings. The packing should be saturated at each lubrication interval.

(b) *Ring Oiling.* Integral horsepower motors may have ring-lubricated sleeve bearings. The rings are located in a slot in the upper half of the bearing and ride loosely on the shaft. There are normally no more than two rings for each bearing. Free turning of the rings should be checked on starting a new motor, at each inspection period, and after maintenance work. The oil level should be such that a 60-degree segment of the oil ring on the inside diameter is immersed while the motor shaft is at rest. A sight glass, constant level oiler, or some other unit is provided to mark and observe the oil level. Levels should be marked for the at-rest condition and the operating condition.

(c) *Bath Oiling.* Large, vertical motors frequently have a surrounding oil bath for lubrication of either rolling element bearings or plate thrust bearings. Horizontal units equipped with ball and roller bearings may also have an oil bath. The proper oil level is determined by the manufacturer and is dependent upon the bearing system. A sight glass or some other unit is provided to mark and observe the oil level. This level may change depending on whether the motor is operating or at rest. It should be marked for both situations.

(d) *Oil Mist Lubrication.* Pressurized oil mist systems are being increasingly used in refinery applications. These normally involve interlocked controls such that the source of mist pressure must be in operation to permit energization of the lubricated motor. Often a single centralized mist source supplies a number of motors. Maintenance should include checking of drain/discharge openings at each bearing to see that pressure can be discharged freely to the atmosphere and that the mist pressure regulation equipment is functioning properly.

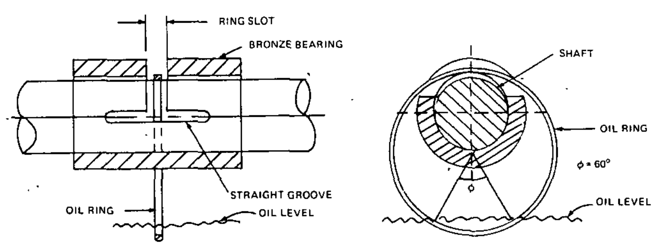

Figure 19-3.7.7(b)

19-3.7.8 Frequency. In oil lubricating systems, it is required that the oil level be maintained. This is observed by means of a sight glass, constant level oiler, etc., and oil is added as required. Normally, these systems should be drained and refilled on an annual basis. Wick oil systems require addition of oil quarterly and the wick should be saturated.

19-3.7.9 Motor Inspections. Visual inspections should be performed on a periodic basis. These inspections are necessary to detect mechanical or lubrication deficiencies before they become serious. The inspection should include a check for increase in temperature, excessive bearing noise, excessive vibration, and lubricant leakage. If any of these conditions exist, the cause should be located and corrected.

19-3.8 Vibration Tests and Analysis.

19-3.8.1 Life of a ball or roller bearing is defined as the number of revolutions or hours of operation at constant speed that the bearing is capable of running before fatigue develops. If a bearing is properly lubricated, mounted, and handled, all causes of failure are eliminated except one, fatigue of the material. These failures initiate with the removal of metal from the races or rolling elements. Vibration-analyzing equipment can be used to predict these failures when it monitors vibration velocity or is able to distinguish vibration displacement as a function of frequency. Such equipment is useful in isolating the source of vibration that may appear to be the result of other malfunctions within a motor. It is also useful for ensuring proper installation of critical production equipment. Antifriction bearings fail due to a loss of oil film resulting from wear, leakage, etc. These failures are sudden; and without constant vibration-monitoring equipment, they cannot be predicted.

19-3.8.2 Vibration analyzers are very handy tools to detect trouble and prevent downtime. A formal vibration analysis program can reduce costly machine failures. The program can range from the use of simple hand-held analyzers to sophisticated multi-channel recorders with permanently mounted sensors to provide data for comparison. Such a program makes it possible to keep track of the condition of rotating equipment, particularly high speed types. Trend charts will assist in establishing maintenance needs. The degree of sophistication depends on the application, but even a hand-held vibrograph is a useful tool in EPM.

19-3.9 Dirt.

19-3.9.1 Where rotating equipment is exposed to dirt, regular inspection is needed to detect when cleaning is needed. A major cause of burned out motors is clogged air passages. On motors in dirty atmospheres, filters (where used) frequently become clogged, therefore, filter cleaning or changing should be scheduled. The external surface of motors should be kept cleaned because a pile-up of dirt restricts heat dissipation. This is particularly important with "T"-frame motors. Refer to Chapter 14 for cleaning methods. In dirty locations and critical applications, more extensive insulation testing may be warranted as described in Chapter 18. Excessive leakage current may well indicate that a motor failure is imminent.

19-3.10 Control for Rotating Equipment.

19-3.10.1 This involves the motor starters, contactors, and other devices that are directly involved with the control of equipment operating over long periods between shutdowns. The maintenance recommendations of Chapter 9 are pertinent to equipment operating for long periods between shutdowns.

19-3.10.2 While the equipment is in operation, EPM procedures must be modified. Where control panels can be opened while energized, any terminals with a voltage greater than 150 volts to ground should be covered with a transparent protective covering to permit visual inspection. Essentially EPM will be limited to visual inspection. Be sure that adequate ventilation is maintained within enclosures. Gaskets should be kept in good repair where used and the atmosphere is dirty. Contact wear should be observed where possible.

19-3.11 Redundancy.

19-3.11.1 Although it is expensive, redundant circuits and equipment are often necessary to ensure continuity of operation. During initial design stages, and even at later times, consideration should be given to what is needed to prevent unscheduled shutdowns and high maintenance costs. Frequently, redundancy of critical circuits provides the solution.

19-3.12 Heating Equipment.

19-3.12.1 In general, this equipment cannot be maintained while it is in operation. Perhaps rotating parts are not involved but certainly there is heat, and the potential of serious burns therefore exists.

19-3.12.2 In most process heating systems, continuous cycling or on-off operation is carried out. This cycling will cause a certain amount of temperature change. As a result, particular attention must be paid to all connections and joints. The use of Belleville washers has been successful in maintaining tight connections. During the time the equipment is in operation, visually inspect all joints and terminations and look for signs of heating or arcing that would indicate loose joints. The cycling frequently will cause some movement of the wiring; therefore, check the insulation on the wiring where it passes through nipples, access holes, and other openings.

19-3.13 Electrostatics — Static Grounding.

19-3.13.1 The purpose of static grounding is to remove the accumulation of static electricity on equipment, on materials being handled or processed, or on operating personnel that can build up during machine operation. On equipment that is in continuous operation, regular inspection and repair procedures should be developed and maintained in order to retain the integrity of the grounding continuity.

Since the static charge can build up to several thousand volts, consideration should be given during the initial construction of equipment to reduce the buildup. Equipment is made up of conductors (metal machine frame) and insulators (conveyor belts, plastic parts, etc.). Usually some part of a machine is grounded either electrically or by virtue of construction. Machine parts may be grounded directly or by bonding them to other machine parts which are grounded. Clean, unpainted metal nuts and bolts holding together clean, unpainted metal parts provide adequate continuity. Bonding and grounding may be accomplished by permanently attached jumper wires. When such wires are attached by lugs or placed under bolt heads or nuts, all parts must be clean and unpainted before installation. Any painting of parts used for static grounding should be done only after such parts are properly installed and the adequacy of the ground is certified. Slowly rotating parts are normally adequately bonded or grounded through the bearings. However, parts rotating at high RPMs, such as baskets or centrifuges, should be bonded or grounded by wipers, carbon brushes, or other devices. Portable equipment can be temporarily grounded by clamping a static ground wire to the equipment.

19-3.13.2 Adequate Static Grounding. It may be necessary to obtain the recommendations of experts in a particular static grounding problem. However, some guidelines that will provide adequate static grounding are listed as follows:

(a) Static charging currents rarely exceed one microampere and often are smaller. Thus, leakage currents of the order of microamperes will provide protection against the accumulation of static electricity to dangerously high potentials.

(b) A leakage resistance between a conductor and ground as high as 10,000 megohms will provide adequate static grounding in many cases. However, when charges are generated rapidly, a leakage resistance as low as one megohm may be necessary.

(c) The leakage resistance necessary for adequate static grounding will vary among different operations and must be established by a qualified authority. In the absence of any specifications, the leakage resistance from any conductor to ground should not exceed one megohm.

(d) There is no electrical restriction in conductor size for static ground wires and jumpers, but larger size conductors may be required to limit physical damage. However, where a conductor used for static grounding is also the equipment grounding conductor for a power circuit, the conductor must be sized in accordance with Table 250-95 of NFPA 70, *National Electrical Code*.

(e) A static ground wire need not be insulated.

(f) Any equipment grounding conductor that is adequate for power circuits is more than adequate for static grounding.

19-3.13.3 Inspection and Maintenance. An inspection and maintenance program is essential in assuring that the integrity of static grounding systems is retained. Inspections should be made only by properly trained personnel. Inspections should consist of both resistance measurements and a visual check.

(a) The resistance from all conductive parts to ground should be measured with a suitable megohmmeter (*see 19-3.13.5*). Corrective measures should be made to bring all resistance values within specifications.

(b) A visual inspection should be made for frayed wires, wires with broken strands, and other physical damage. Such damage should be repaired regardless of measured resistance values.

19-3.13.4 Inspections should be made of all new installations and whenever alterations are made to or parts replaced in an installation. Inspections should be made at regular intervals. The frequency of regular periodic inspections must be determined from experience. Inspections should be most frequent in areas where corrosion is a problem and in areas classified as hazardous.

19-3.13.5 Megohmmeters. A suitably calibrated resistance measuring device having a nominal open-circuit output voltage of 500 volts dc and a short-circuit current not exceeding 5 mA should be used to check static grounding systems. If inspections are made in hazardous (classified) locations, the megohmmeter should be of an intrinsically safe type.

19-3.13.6 Recordkeeping. Precise records should be made and retained of the results of all inspections and of the corrective actions taken. Precise records will aid in determining the necessary inspection frequency and point out weak spots in the static grounding system that may need modification.

19-3.13.7 Precautions During Inspections. If inspections and corrective measures must be made when flammable vapors are apt to be present, certain precautions must be taken by the inspector and maintenance personnel.

(a) Care must be taken that personnel are adequately grounded to prevent a dangerous accumulation of static electricity on their bodies.

(b) Care must be taken that no spark discharge occurs between improperly grounded conductors and personnel, instrumentation or tools.

(c) Only nonferrous, nonsparking tools should be used in the area.

19-3.13.8 Typical Checkpoints for Inspection.

(a) All conductors in a hazardous area must be inspected for adequate static grounding.

(b) Since machines and operations differ considerably, a checklist should be prepared of all points to be checked. The following are typical for many machines and operations:

1. Permanently installed jumper wires.
2. Static ground wires and clamps used for the temporary grounding of portable and mobile equipment.
3. Metal hose couplings.
4. Metal hose clamps.
5. Metal bolts and nuts used to connect sections of either conductive or nonconductive pipes and ducts.
6. All sections of metal pipes and ducts.
7. Rotating parts and shafts.
8. Rotating baskets of centrifuges.
9. Handles and stems of ball valves and plug valves.

(c) All rotating parts should be checked while in motion.

19-4 Process Instrumentation and Control.

19-4.1 General. The systems and equipment covered by this section are the following: power supplies; interlock and logic systems; safety and shutdown systems; sensing, control and indicating systems; and alarm systems.

19-4.2 Design to Accommodate Maintenance.

19-4.2.1 Section 5-1 of this recommended practice has stated that, except for limited visual inspection such as observing operating temperatures, examination for contamination, recording load readings, etc., the apparatus must be taken out of service to perform efficient and effective maintenance. Further, unless flexibility is built into the system in the way of duplication or alternate transfer schemes, maintenance of vital electrical apparatus must be scheduled with planned production outage.

19-4.2.2 The importance of identifying and designing for the vital elements of the process control system cannot be overstressed. The elements of the process instrumentation and control system that must be inspected, tested, or maintained while the plant or process remains in operation must be identified in the design stage. The necessary duplication of facilities and provision for test and inspection should be provided.

19-4.2.3 Examples of such provisions are alternate power sources to permit shutdown and inspection of normal power sources, bypass switches for inverters, provisions for on-stream function-testing of shutdown circuits, provision of dual sensing components for critical controls, test circuits to permit simulation of alarm conditions, and monitoring devices for important interlock and logic systems. Selection of quality equipment is also mentioned in Section 5-1 as a means of reducing maintenance requirements. Again, the importance of long run facilities cannot be overemphasized.

19-4.2.4 Whenever possible, control modules should be plug-in type, replaceable with normal precautions and procedures. Test and adjustment of major components should be possible without disconnection or removal from enclosures and with use of standard instruments such as volt-ohm-milliammeter and oscilloscope.

19-4.2.5 Cabinets should be fully compartmented to allow maintenance access to sections not in service without risk to personnel or continuity of service. For instance, the inverter, standby transformer/voltage regulator and transfer switch power supply should be in physically separate compartments. Removal or replacement of components in one cabinet section should not require access to other sections.

19-4.3 Power Supplies.

19-4.3.1 Power supplies can be divided into two categories: power supplies normally in service; and standby or emergency power supplies.

19-4.3.2 Power supplies that are normally in service should be inspected on a regular basis. This inspection would include the following typical checks and inspections:

(a) Reading of meters to detect changes in or abnormal load or voltage conditions.

(b) Check of ground detection equipment for presence of grounds.

(c) Integrity of trip and transfer circuits where monitoring lights are provided.

(d) State of charge on batteries.

(e) Battery charger supply and output load and voltages.

(f) Visual inspection of accessible current-carrying parts for signs of overheating.

(g) Check on equipment environment for heat, moisture, or dust that exceeds the conditions for which the equipment is designed.

19-4.3.3 The inspection interval may be daily, weekly, or monthly, depending on equipment environment and operating conditions. Tasks such as reading of meters and checks on monitoring lights may be incorporated as part of a daily walk-through inspection.

19-4.3.4 Where redundancy in facilities is provided, equipment components should be taken out of service for a thorough inspection and testing and for any required maintenance at intervals dictated by service and operating conditions. The initial interval should be in line with manufacturer's recommendations and later shutdowns scheduled in line with the as-found condition of the equipment.

19-4.3.5 Where power supply components are in standby or emergency service, periodic testing should be carried out to ensure that the standby equipment is ready to function and can assume the supply function. This requires periodic startup of emergency generators, operation of auto-transfer switches, etc. Testing should simulate actual operating conditions as closely as possible. For critical facilities, testing intervals such as once a week are suggested.

19-4.3.6 Where it is possible to put critical standby facilities in operation to supply the normal load without disturbing plant operations, the standby facilities should be switched in at regular intervals and operated for a sufficient period to ensure they are functioning properly. An interval of once a month is suggested for operating standby facilities. Where standby facilities are fully rated, they may share operating time on an equal basis with the normal supply.

19-4.4 Interlock and Logic Systems.

19-4.4.1 Maintenance procedures on interlock and logic systems are limited to visual inspections of components and wiring and checks on monitoring devices unless design features permit onstream functional testing. Also, in some plants, the process operation or equipment arrangement permits periodic function testing.

19-4.4.2 Where functional testing can be done and where the system does not function during normal operations, once a week function testing is suggested for systems whose failure can result in hazard to personnel, fire, damage to equipment or serious degradation or loss of product. Systems of lesser importance should be tested initially on a once-per-month basis with subsequent testing intervals determined by experience and assessment of operating environment.

19-4.5 Sensing, Indicating, and Control Systems.

19-4.5.1 The need for and frequency of inspection and maintenance is determined by the effect on safety, plant operations, and the severity of service. Also, some components can be readily isolated while others can be inspected only during plant or process shutdowns.

19-4.5.2 Visual inspection either by plant operators during normal operations or as part of a scheduled inspection can assist in detection of deficiencies such as loose connections, overheating, excessive vibration, etc.

19-4.5.3 Sensing, indicating, and control devices can be divided into two categories:

(a) *Primary Elements.* Elements in contact with the process medium directly or indirectly and that may or may not be isolated from the process medium.

(b) *Secondary Elements.* Transmitting, recording, or controlling devices. Some are normally in use and, through this use, are receiving an automatic day-to-day check. Some are remotely located or infrequently used and require a check at regular intervals.

19-4.6 Level Devices.

19-4.6.1 Primary devices installed within process vessels can only be checked with the vessel out of service. Visual inspection should indicate need for maintenance.

19-4.6.2 Where the device can be isolated from the process, visual inspection should be made at least once a year and more frequently if extreme accuracy is needed or the service is severe or critical.

19-4.7 Temperature Devices.

19-4.7.1 Primary devices are generally installed in wells and can be checked at any time the device appears to be malfunctioning. The well should be visually inspected at each plant shutdown and necessary maintenance carried out.

19-4.7.2 The secondary device or instrument can usually be checked at any time without seriously affecting normal operations.

19-4.8 Pressure Devices.

19-4.8.1 Primary devices usually have block valves to permit isolation from the process and checking at any time malfunction is indicated.

19-4.8.2 Secondary devices can usually be isolated from the primary device and checked at any time.

19-4.8.3 Process impulse connections should be checked during equipment shutdown.

19-4.9 Indicating, Recording, and Controlling.

19-4.9.1 Signal Receivers. Checks are limited to day-to-day observation of performance by plant operators. Receiver construction usually permits substitution of spare units for faulty units.

19-4.10 Safety and Shutdown Systems.

19-4.10.1 On-line testing facilities for safety and shutdown systems should be provided in all designs. Where practical, the facilities should include multiple sensors and safe bypass systems around the final control element. This permits testing of the entire shutdown circuit.

19-4.10.2 Safety and shutdown circuits should be tested in the range of one-per-shift to once-per-week unless the circuit functions regularly in normal operation. This may be the case for some shutdown circuits.

19-4.10.3 Because of the frequency of testing, these functional tests may be part of the plant operators' normal duties with maintenance personnel involved only if problems are indicated.

19-4.11 Alarm Systems.

19-4.11.1 Alarm systems are usually equipped with lamp test switches that permit checking lamp and alarm circuit integrity at any time during normal operation. These tests should be made on a once-per-shift to one-per-day basis to detect lamp burnout or circuit defects in alarms that operate infrequently. This can be done as part of the plant operators' normal duties with maintenance personnel involved only if further attention is needed.

19-4.11.2 Alarms for critical conditions that may result in hazard to personnel, fire, equipment damage, or serious degradation or loss of product should be function-tested at regular intervals. A once-per-week to once-per-month interval is suggested depending on the importance and vulnerability of the alarm devices to hostile environments. Function testing required that either provision be made in the system design for the testing facilities or that it be possible to test by manipulating the process variable or otherwise simulate the alarm conditions.

19-4.12 Wiring Systems.

19-4.12.1 These systems can be visually checked for loose connections, proper grounding and shielding, and signs of deterioration or corrosion. Usually maintenance during plant operation is limited to circuits that malfunction or show evidence of possible malfunction.

Chapter 20 De-energizing and Grounding of Equipment to Provide Protection for Electrical Maintenance Personnel

20-1 General.

20-1.1 Personnel working on, or in close proximity to, de-energized lines or conductors in electrical equipment should be protected against shock hazard and flash burns that could occur if the circuit were to be inadvertently re-energized. Sound judgment should be exercised when deciding on the extent of protection to be provided, and determining the type of protective equipment and procedures that should be applied.

The extent of protection that should be provided will be dictated by specific circumstances. Optimum protection should be provided. A high level of protection should be provided for any work on high- and medium-voltage circuits; on the other hand, minimal protection may be sufficient for work on minor branch circuits. Balance must be struck between the two extremes of optimum and minimal-but-adequate protection.

The following possible conditions and occurrences should be considered in determining the type and extent of protection to be provided:

1. Induce voltages from adjacent energized conductors; these can be appreciably increased when high fault currents flow in adjacent circuits.

2. Switching errors causing inadvertent re-energizing of the circuit.

3. Any unusual condition that might bring an energized conductor into electrical contact with the deenergized circuit.

4. Extremely high voltages caused by direct or nearby lightning strikes.

5. Stored charges from capacitors or other equipment.

20-1.2 Providing proper protection should include, but not necessarily be limited to, the following five basic steps.

1. De-energize the proper circuit. Check applicable up-to-date drawings, diagrams and identification tags to determine all possible sources of supply to the specific equipment. Open the proper disconnecting device for each source. In cases where visible blade disconnecting devices are used, visually verify that all blades are fully open. Drawout-type circuit breakers should be withdrawn to the fully disconnected position. Do not consider automatic switches or control devices to be disconnecting means for personnel safety.

2. Take precautions to guard against accidental re-energization. Attach to the operating handles of the open disconnecting devices locks and HOLD tags with sufficient information thereon. If fuses have been removed to de-energize the equipment, special precautions should be taken to prevent their unauthorized reinsertion. An established lock and tag policy is an essential part of any electrical maintenance safety program.

3. Test the circuit to confirm that all conductors are de-energized. This test is especially important on circuits that involve switches and fixed-type circuit breakers in which the blades cannot be visually checked. Use an adequately rated voltage detector to test each de-energized circuit for NO VOLTAGE. BEFORE and AFTER testing the affected conductors, determine that the voltage detector is operating satisfactorily by proving it on a source that is known to be energized. Some high- and medium-voltage detectors are equipped with a device that will provide the necessary proof voltage.

4. Until they are grounded, conductors should be considered energized and personnel should not touch them. If the test indicates there is NO VOLTAGE on the affected conductors, they should then be adequately grounded in accordance with established procedures. Ground the conductors to protect personnel in event that, in spite of all precautions, the equipment does become re-energized. When capacitators are involved, they should be grounded and shorted to drain off any stored charge.

5. Involve all personnel connected with the work. Each individual should personally satisfy himself that all necessary steps have been executed in the proper manner.

20-1.3 In spite of all precautions, de-energized circuits can be inadvertently re-energized. When this occurs, adequate grounding is the only protection for personnel working on them. For this reason, it is especially important that adequate grounding procedures be established and rigidly enforced.

There are those who still hold to the old mistaken idea that grounding de-energized power conductors with a chain or small-diameter wire and battery clamps provides adequate safety for personnel. Such practices were not safe 50 years ago when power systems were relatively small; they certainly are not safe on modern systems that are much larger and capable of delivering hundreds of thousands of amperes into a fault. Such currents can easily vaporize a chain or small grounding conductors without blowing fuses or opening a circuit breaker, thereby exposing personnel to dangerous voltages, vaporized conductor metal, and serious power arcs. In the interest of protecting lives, adequate grounding procedures and equipment that ensure positive personnel protection are essential.

A variety of terms is used to identify the grounding of de-energized electrical equipment to permit personnel to safely perform work on it without using special insulated tools. Some of these terms are "safety grounding," "temporary grounding," and "personnel grounding." Throughout this chapter, the word "grounding" is used to refer to this activity; it does not refer to permanent grounding of system neutrals or noncurrent-carrying metal parts of electrical equipment.

Grounding equipment consists mainly of special heavy-duty clamps that are connected to cables of adequate capacity for the system fault current. This current may well be in excess of 100,000 amperes that will flow until the circuit overcurrent protective devices operate to de-energize the conductors. The grounding equipment should not be larger than necessary, because bulkiness and weight hinder personnel while connecting them to the conductors, especially while working with hot-line sticks. Five major considerations in selecting grounding equipment are:

1. Grounding clamps should be of proper size to fit the conductors and have adequate capacity for the fault current. An inadequate clamp can melt or be blown off under fault conditions.

Hot-line clamps should not be used for grounding deenergized conductors because they are not designed to carry the high current that would flow if the circuit were to be inadvertently re-energized. They are intended to be used only for connecting tap conductors to energized overhead lines by means of hot-line sticks and are designed to carry only normal load current. If hot-line clamps are used for grounding, high fault current could melt or blow them off without operating the overcurrent protective devices to de-energize the conductors, thereby exposing personnel to lethal voltages and arc burns.

2. Grounding cables should be of adequate capacity which, in some instances, may require two or more to be paralleled. Three factors that contribute to adequate capacity are: (1) terminal strength, which largely depends on the

ferrules installed on the cable ends, (2) size to carry maximum current without melting, and (3) low resistance to keep the voltage drop, across the areas in which the personnel are working, at a safe level during any period of inadvertent re-energization.

3. Solid metal-to-metal connections are essential between grounding clamps and the de-energized conductors. Conductors are often corroded and are sometimes covered with paint. Ground clamps should have serrated jaws because it is often impractical to clean the conductors. The clamps should be slightly tightened in place, given a slight rotation on the conductors to provide cleaning action by the serrated jaws, and then be securely tightened. Ground clamps that attach to the steel tower, switchgear, or station ground bus are equipped with pointed or cupped set screws that should be tightened to ensure penetration through corrosion and paint, to provide adequate connections.

4. Grounding cables should be no longer than is necessary to keep resistance as low as possible and to minimize slack in cables to prevent their violent movement under fault conditions. If the circuit should be inadvertently re-energized, the fault current and resultant magnetic forces could cause severe and dangerous movement of slack grounding cables in the area where personnel are working. Proper routing of grounding cables to avoid excessive slack is essential for personnel safety.

5. Grounding cables should be connected between phases to the grounded structure and to the system neutral (when available) to minimize the voltage drop across the work area if inadvertent re-energization should occur. The preferred arrangement is shown in Figure 1 with the equivalent electrical diagram of same.

Connecting the phase conductors together with short cables and clamps of adequate capacity, as shown in Figure 1, minimizes resistance between phases for fast action of the circuit overcurrent protective devices to de-energize the circuit, if it should be inadvertently re-energized. The short "down lead" cable between the jumpered phase conductors and the grounded tower or switchgear ground bus reduces resistance to ground and the amount of cable that can move violently in the work area during high current flow. If there is a system neutral conductor at the work location, a cable should also be connected to it for more complete protection and to ensure lowest resistance in the ground return path to the source. Figure 1 shows buses and a person working inside switchgear; the same conditions would apply to personnel on overhead line towers and outdoor substanchion steel structures. When someone is working on such properly grounded areas, he is in parallel with a minimum of resistance so he would be exposed to minimum voltage drop in event of current flow in the system, and the low resistance would cause rapid operation of the fuses or circuit breakers, thus minimizing the time the person is exposed to the voltage drop.

Prior to installing grounding equipment, it should be inspected for broken strands in the conductors, loose connections to the clamp terminals and defective clamp mechanisms. Defective equipment should not be used.

Grounding equipment should be installed at each point where work is being performed on de-energized equipment. Often it is advisable to install grounding equipment on each side of a work point or at each end of a de-energized circuit.

One end of the grounding "down lead" should be connected to the metal structure or ground bus of the switchgear before connecting the other end to a phase conductor of the de-energized equipment. Then, and only then, should the grounding cables be connected between phase conductors.

When removing grounding equipment, the above installation procedure should be reversed by first disconnecting the cables between phases, then disconnecting the "down lead" from the phase conductor and, finally, disconnecting the "down lead" from the metal structure or ground bus.

Removal of grounding equipment before the circuit is intentionally re-energized is equally as important as was its initial installation but for other reasons. If grounding equipment is forgotten or overlooked after the work is completed and the circuit is intentionally re-energized, the supply circuit overcurrent protective devices will immediately open because the conductors are jumpered and grounded. The short-circuit current can damage the contacts of a breaker having adequate interrupting capacity and can cause an inadequate breaker or fuses to explode. If the grounding cables are inadequate, they can melt and initiate damaging power arcs. A procedure should be established to assure removal of all grounding equipment before the circuit is intentionally re-energized. Recommendations for such a procedure are:

(a) Assign an identification number to each grounding equipment set and rigidly control all sets that are available for use by all parties, including contractor personnel. Record the number and location of each set that is installed. Cross that number off the record when each set is removed.

(b) Before re-energizing the circuit, account for all sets of grounding equipment by number to assure that all have been removed.

(c) Do not install a set of grounding equipment inside switchgear and then close the door or replace the covers so it will be hidden from view. If it is necessary to so conceal grounding equipment, place a highly visible sign on the door or cover to remind personnel that a ground is inside.

(d) Before re-energizing, have personnel inspect interiors of equipment to verify that all grounding sets, including small ones used in testing potential transformers, relays, etc., have been removed.

(e) Before re-energizing, test all conductors with a megohmmeter to ascertain if any are grounded. If so, determine the cause and take corrective action.

Use of insulated hot-line sticks, rubber gloves, or similar protective equipment by personnel is advisable while installing grounding equipment on ungrounded de-energized overhead line conductors and also while removing the grounding equipment.

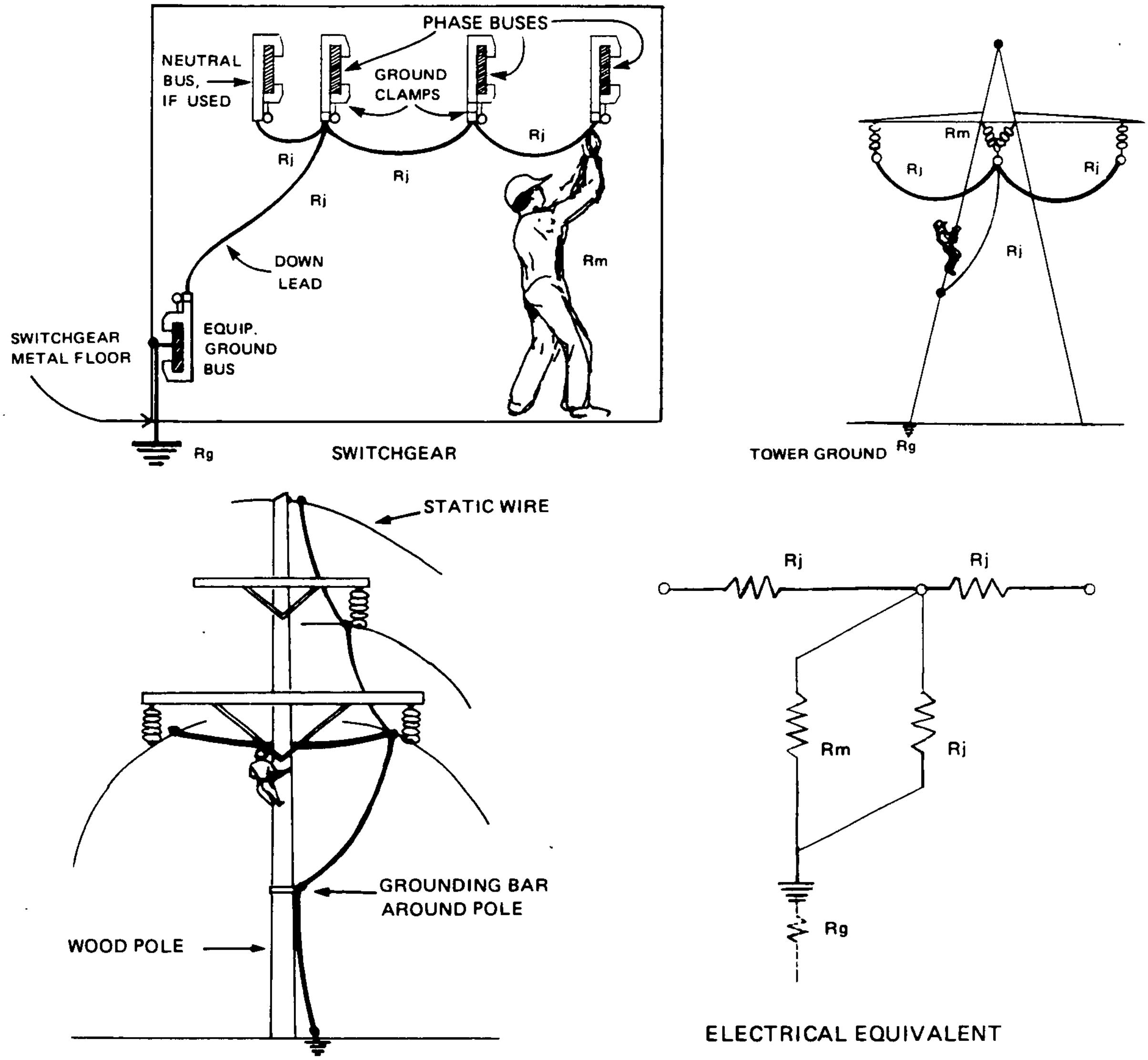

Figure 1 Preferred Grounding Arrangement

Presume that, in Figure 1 equivalent diagram, the resistance of the person's body Rm is 500 ohms. He is in parallel with only the resistance of a single cable Rj which can be in the order of .001 ohm. Rg is the ground resistance of the switchgear or structure area. If a 1,000-amp current should flow in the circuit grounded in this manner, the person would be subjected to only about 1 volt imposed across the work area; therefore, the current flow through his body would be negligible. Compare this with the nonpreferred grounding arrangement shown in Figure 2 in which each conductor is connected to a driven ground rod.

Refer to data available from grounding equipment manufacturers for ampacities of cables and clamps and for detailed application information.

In some instances, specialized grounding equipment may be required, such as traveling grounds on new overhead line conductors being strung adjacent to energized circuits.

Drawout-type grounding and testing devices are available for insertion into some models of switchgear to temporarily replace circuit breakers; they provide a positive and convenient grounding means for switchgear buses or associated circuits by connecting to the switchgear buses or line stabs in the same manner as drawout breakers. One such device has two sets of primary disconnecting stabs; one, designated "BUS," connects to the switchgear bus stabs, and the other set, designated "LINE," connects to the switchgear supply line or load circuit stabs. Another type of grounding device has only one set of primary disconnecting stabs that may be positioned to connect to either the switchgear "BUS" stabs or the "LINE" stabs.

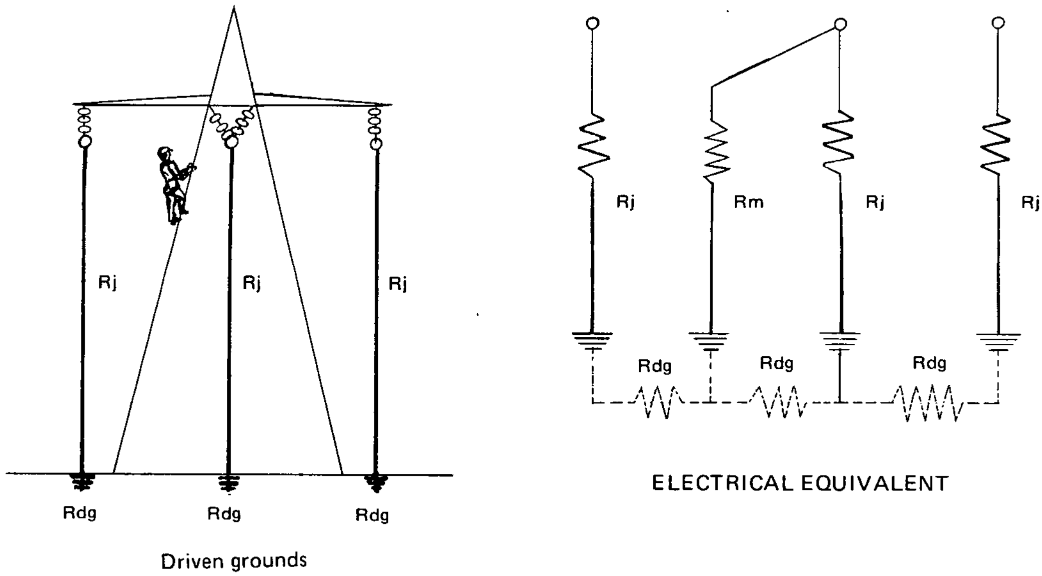

Figure 2 Nonpreferred Grounding Arrangement

In Figure 2 equivalent diagram, the person's resistance Rm of 500 ohms is in parallel with the resistance of the jumper cable Rj and the resistance of the structure area and driven grounds Rdg in series; these can easily total 1 ohm. The increased resistance in this grounding arrangement can make an appreciable difference in the voltage drop. If a 1,000-amp current should flow in the circuit grounded in this manner, the person would be subjected to 1,000 volts imposed across the work area.

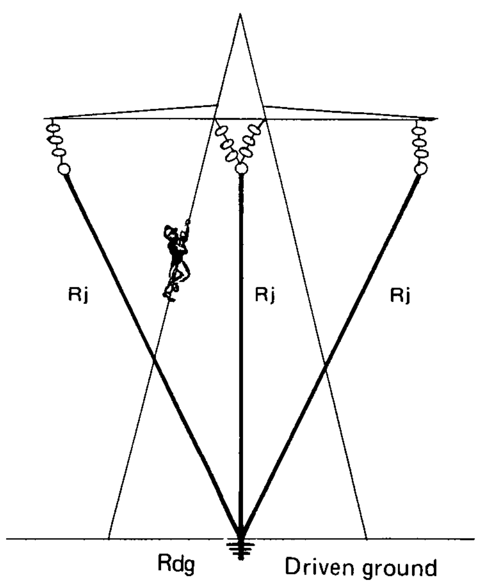

Figure 3 Nonpreferred Grounding Arrangements

Figure 3 is another nonpreferred grounding arrangement. All three grounding cables are connected to a common driven ground. This reduces the resistance Rg between phases to practically 0 ohm which would enable the overcurrent protective devices to de-energize the circuit rapidly. However, the driven ground resistance Rdg is still in parallel with the work area, so the voltage drop across the person would be high.

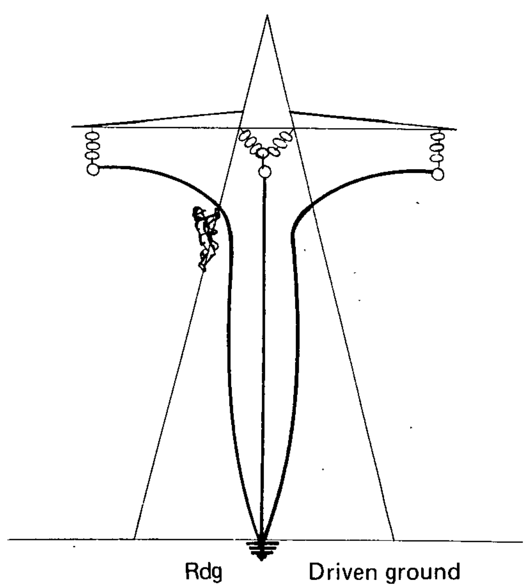

Figure 4 Nonpreferred Grounding Arrangements

Figure 4 is electrically the same as Figure 3 but placing the cables close together for convenience results in slack which can move violently in the work area during periods of high current flow. Therefore, this is not a preferred arrangement.

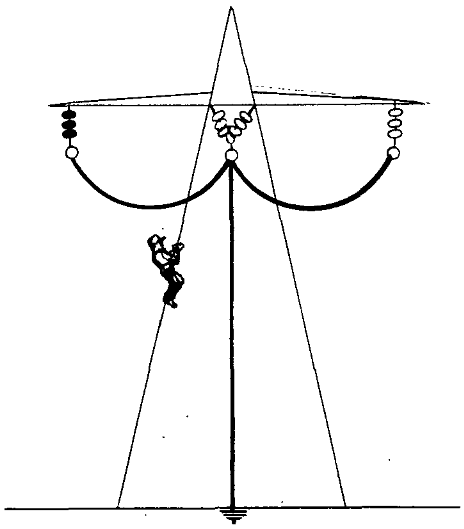

Figure 5 Nonpreferred Grounding Arrangements

Figure 5 is not a preferred arrangement. Even though low resistance between phases would enable the overcurrent protective devices to de-energize the circuit rapidly, and there is only one down lead Rj to a driven ground Rdg, the ground resistance remains high, so the voltage drop across the person would be too high for personal safety.

Grounding cables may be connected from the selected disconnecting stud terminals in one of these devices to the switchgear ground bus. When the device is fully inserted into the switchgear, it grounds the de-energized buses or lines that were previously selected. Utmost care should be exercised when using these devices to prevent the inadvertent grounding of an energized bus or circuit. Such a mistake could expose personnel to flash burns and seriously damage the switchgear. Before inserting a device with grounding cables connected thereto into switchgear, it is essential that the stabs that are to be grounded are tested for NO VOLTAGE, and to verify that only the proper and matching disconnecting stud terminals in the device are grounded.

Chapter 21 Cable Tray System

21-1 General.

21-1.1 A cable tray system is a unit or assembly of units or sections and associated fittings made of metal or other noncombustible materials forming a rigid structural system used to support cables. Cable tray systems include ladders, troughs, channels, solid bottom trays, and other similar structures.

21-1.2 The frequency of maintenance will depend on the environment in which the cable tray is installed. In areas of heavy industrial contamination or coastal areas, frequent inspections may be necessary.

21-2 Cable.

21-2.1 Cable insulation should be visually inspected for damage. Among the factors that may cause insulation damage are sharp corners, protuberances in cable tray, vibration, and thermal expansion and contraction.

21-2.2 Cable insulation should be tested in accordance with Chapter 8.

21-2.3 The number, size, and voltage of cables in cable tray should not exceed that permitted by NFPA 70, *National Electrical Code*, Article 318. Communication or data processing circuits are susceptible to interference problems when mixed with power circuits.

21-3 Cable Tray.

21-3.1 Inspect cable tray for intrusion of such items as pipe, hangers, or other equipment that could damage cables.

21-3.2 The deposits of dust, industrial process materials, and trash of any description should be checked and evaluated in terms of reduced ventilation and potential fire hazard.

21-3.3 Bolted connections between sections should be visually checked for corrosion and a sample retorquing done in suspect areas.

21-3.4 Certain atmospheric conditions may create fastener failure; therefore, a visual inspection should check for missing or damaged bolts, bolt heads, or nuts. Where necessary, they should be replaced with suitable hardware.

21-3.5 Visually and mechanically check adequacy of cable tray grounding and bond between cable tray and all takeoff raceways.

21-3.6 Covers should be inspected to assure that physical damage does not reduce spacings or damage cables.

21-4 Low-Voltage (600 V) Busway.

21-4.1 General.

21-4.1.1 For the purpose of this section, a busway is considered to be a grounded metal enclosure containing factory-mounted, bare or insulated conductors that are usually copper or aluminum bars, rods, or tubes.

21-4.2 Electrical Joints.

21-4.2.1 A sample check of bolts for tightness should be conducted. Where Belleville spring washers are used and visible, they should be checked for flatness that indicates tightening to proper torque.

21-4.2.2 Infrared inspection of the busway can reveal abnormal temperatures and potential problem areas and should be performed in accordance with Section 18-16.

21-4.3 Housing.

21-4.3.1 Visually check to see if all joint covers and plug-in covers are in place and tight. This will prevent accidental contact with energized conductors. Joint covers may also be essential for continuity of ground path between sections.

21-4.3.2 Remove trash, combustible material, and other debris from a busway. Ventilation openings should be clear.

21-4.3.3 On an indoor busway, visually check for evidence of exposure to liquids and eliminate source or provide necessary protection.

21-4.3.4 On an outdoor busway, visually check to ascertain if weep hole screws have been removed in accordance with manufacturer's instructions.

21-4.4 Plugs.

21-4-4.1 Check circuit breaker and fusible plugs for proper operation.

21-4.4.2 Check plug hangers for tightness to ensure proper grounding.

21-4.4.3 If plug installation requires hook sticks for operation, check for hook stick availability.

21-4.5 Conduit and Raceways.

21-4.5.1 Visually check cable and raceways for proper bonding to fittings (plugs, tap boxes).

21-4.6 Testing.

21-4.6.1 Insulation-resistance testing should be performed in accordance with 18-9.2.1.

21-4.6.2 If there is uncertainty concerning the adequacy of the insulation after insulation-resistance testing, a high-potential test should be conducted. (*See 18-9.3.1.*) Normal high-potential voltages are twice rated, voltage plus 1000 volts for one minute. Since this may be above the corona starting voltage of some busways, frequent testing is undesirable.

21-5 Metal-Enclosed Busway (5-15 kV).

21-5.1 General.

21-5.1.1 Busway over 600 V is referred to as metal-enclosed busway. Rated 5 kV and 15 kV, it consists of three types: isolated phase, segregated phase, and nonsegregated phase. Isolated phase and segregated phase are utility-type busways used in power-generation stations; industrial plants use nonsegregated phase for connection of transformers and switchgear and interconnection of switchgear lineups.

21-5.2 Electrical Joints.

21-5.2.1 A sample check of bolts for tightness should be conducted. Where Belleville spring washers are used and visible, they should be checked for flatness that indicates tightening to proper torque.

21-5.2.2 Infrared inspection of the busway can reveal abnormal temperatures and potential problem areas and should be performed in accordance with Section 18-16.

21-5.3 Insulators.

21-5.3.1 Visually inspect bus supports for dirt or tracking. Clean dirty insulators; replace insulators that are cracked or show evidence of tracking.

21-5.4 Heaters.

21-5.4.1 Check for proper operation of space heaters. Ammeters in heater supply circuits provide means for quick and frequent observation for proper heater loads to determine if one or more heater units are defective.

21-5.5 Housing.

21-5.5.1 All covers should be in place and properly tightened.

21-5.5.2 Visually check for bonding of bus and equipment to which it is connected.

21-5.6 Testing.

21-5.6.1 Insulation resistance tests should be performed in accordance with 18-9.2.1.

21-5.6.2 High-potential tests in accordance with IEEE 27 should be conducted at 75 percent of the rated insulation withstand levels that follow:

Metal-Enclosed Bus Nominal Voltage (kV, RMS)	Insulation Withstand Level (kV, RMS) *	High-Potential Field Test (kV, RMS) **
4.16	19.0	14
13.8	36.0	27
23.0	60.0	45
34.5	80.0	60

*1 minute
**75 percent of insulation withstand level

Chapter 22 Uninterruptible Power Supply (UPS) Systems

22-1 General. The basic function of uninterruptible power supply (UPS) systems is to preserve power to electrical or electronic equipment. Most UPS systems are

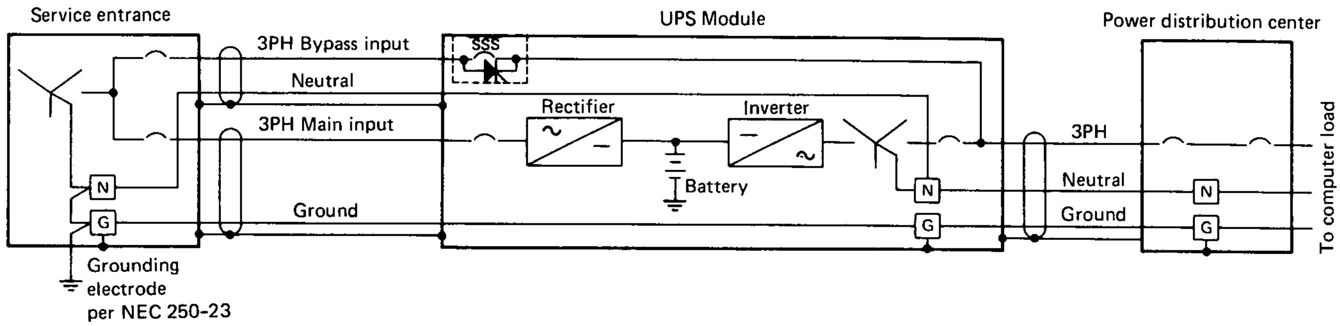

Figure 22-1.1.4(a)

intended to provide regulated power to prevent power supply fluctuations or aberrations that can damage or cause malfunction of sensitive electrical/electronic equipment, such as computers and process controllers. A UPS system represents a sizable investment in equipment specifically installed to provide reliable regulated power to equipment. Therefore it is essential that the UPS be maintained in a manner that the UPS itself will not fail.

The general recommendations in this chapter can be applied to all UPS systems; however, it should be noted that UPS systems are very equipment-specific. As a result, manufacturer's instructions should be followed carefully when performing any maintenance on UPS equipment.

The maintenance program should be planned at the time the UPS system is put into service to provide early attention to ensure a continuing reliable system. The development of an EPM program should not be deferred.

Maintenance should be scheduled at times that will least affect operations. Actual maintenance procedures should not be started until the users have been notified.

Only fully trained and qualified persons with proper test equipment should perform UPS maintenance.

22-1.1 Types of UPS Systems.

22-1.1.1 There are two basic types of UPS systems: static and rotary. Some systems are hybrid versions incorporating some features of both. A basic rotary system is essentially a motor-generator set that provides isolaton between the incoming power supply and the load, and buffers out power supply aberrations by flywheel mechanical inertia effect.

22-1.1.2 A static unit rectifies incoming ac power to dc, and then inverts the dc into ac of the proper voltage and frequency as input power to the load. A battery bank connected between the rectifier and inverter sections ensures an uninterrupted supply of dc power to the inverter section.

22-1.1.3 In the UPS industry, the term "module" refers to a single self-contained enclosure containing the power and control elements needed to achieve uninterrupted operation. These components include transformers, rectifier, inverter, and protective devices.

22-1.1.4 UPS systems can consist of one or more UPS modules connected in parallel to either increase the capacity of the system power rating or to provide redundancy in the event of a module malfunction or failure. Figure 22-1.1.4(a) illustrates a typical single-module static three-phase UPS configuration.

NOTE: In this configuration the solid-state switch (SSS) is internal to the UPS module.

Figure 22-1.1.4(b) illustrates a typical multi-module static three-phase UPS configuration.

NOTE: In this configuration the SSS is located in the stand-alone static transfer switch (STC) control cabinet.

22-1.2 Components to be Maintained. Almost all UPS systems comprise these common elements: disconnecting means, bypass and transfer switches, and protective devices—power switchgear, molded-case circuit breakers, and fuses. Depending on the type of UPS (static, rotary, or hybrid), the system might also include transformers, batteries, battery charger, a rectifier/inverter unit (static system), and motor-generator set (rotary system). The system might also be supported by a standby generating unit to permit operations to continue during sustained power outages.

22-2 UPS System Maintenance Procedures.

22-2.1 General. The routine maintenance procedures for components of UPS systems are covered in the particular equipment sections of this publication (i.e., switches,

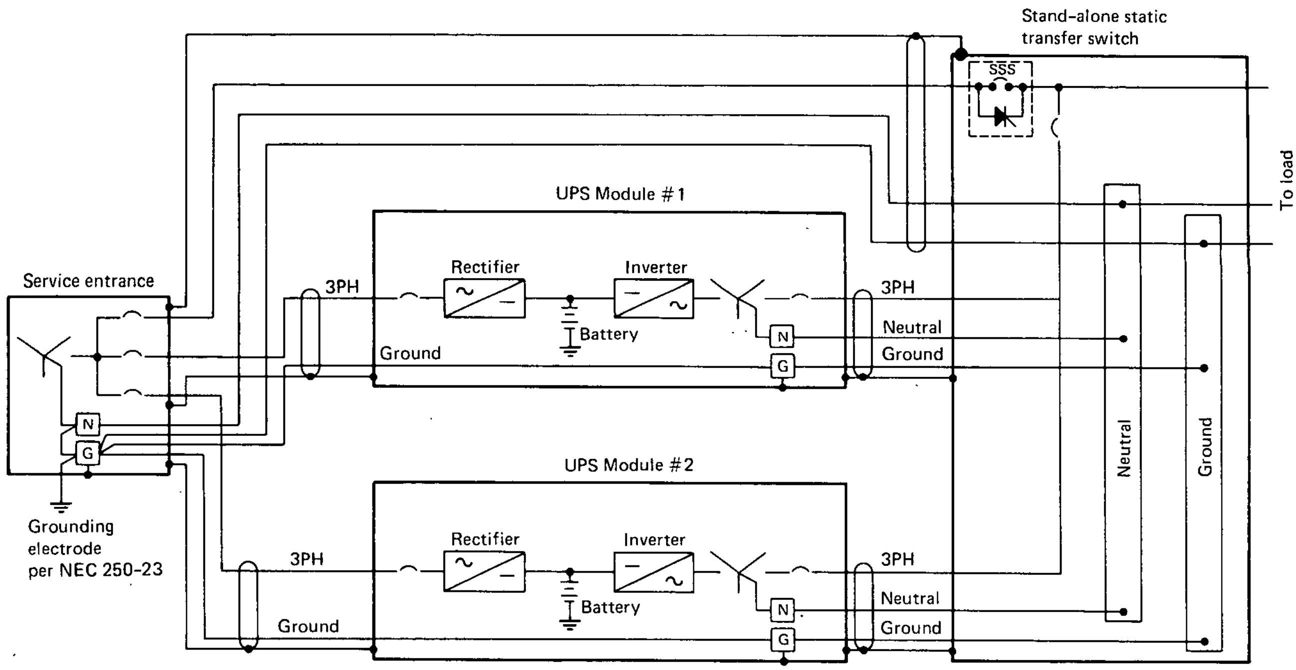

Figure 22-1.1.4(b)

transfer switches, motor controllers, protective devices, batteries and battery chargers, transformers, rotating equipment, etc.).

CAUTION: It is important to avoid interruption of the power output of the UPS system. Extreme caution should be used when servicing the system to prevent unscheduled outages.

However, to aid in an organized preventive maintenance program, the following procedures are recommended.

22-2.1.1 Disconnecting Means and Bypass Switches. These elements of the system should be maintained in accordance with the general maintenance procedures prescribed for the particular device in this document or the manufacturer's instructions as applicable.

22-2.1.2 Transfer Switches. Transfer switches in UPS systems can be of either the manually-operated or automatic type. Switching devices should be maintained in accordance with the appropriate sections of this document. If of the static type, they should be maintained in accordance with the general procedures for maintaining electronic equipment in Chapter 10, and specific procedures provided by the manufacturer. Transfer switches should also be maintained in accordance with manufacturer's guidelines.

22-2.1.3 Circuit Protective Devices. Molded-case circuit breakers should be maintained in accordance with Chapter 11, fuses in accordance with Section 13-1, and other protective devices should be maintained in accordance with Chapter 6. It is especially important to keep an ample supply of the proper types of spare fuses on hand. UPS systems are generally protected with special fuses. Installing an improper fuse on a UPS can result in severe damage to the UPS and the load equipment.

22-2.1.4 Batteries and Chargers. Batteries and chargers should be maintained in accordance with manufacturer's instructions. See Chapter 6 for lead acid batteries and chargers.

22-2.1.5 UPS Support Standby Generator. If the UPS is supported by a standby generating unit, the generator should be maintained in accordance with the general procedures for maintaining rotating equipment in Chapter 14. It is important that a program should be in effect to ensure that the generating unit will be test-run on a regular basis, and also be subjected to a full-load test at least monthly for a minimum of two hours. In addition, generator startup, transfer, restoration of power, retransfer, and auxiliary generator shutdown operation should be checked at least twice a year.

22-2.1.6 UPS Ventilation. Inspect ventilation air filters on a regular basis. The frequency of cleaning or replacement depends on the amount of dust or dirt in the air at the installation and could range from as little as a week to as much as six months.

22-2.1.7 UPS Recordkeeping. It is extremely important that a complete and thorough log book be maintained for the UPS in a suitable location. The log book should be used to record all items concerning the UPS including:

(a) System operation-normal settings and adjustments.

(b) Meter readings such as voltmeter, ammeter, and frequency meter at input and output, taken on a weekly basis (more frequently as required).

(c) Record of abnormal operations, failures, and corrective action taken.

(d) Maintenance history.

This log should be used for comparison to detect changes and degradation of the UPS circuitry, need for adjustment of controls, or other maintenance and testing. Schematics, diagrams, operating procedures, record drawings, spare parts lists, troubleshooting techniques, maintenance procedures, etc., should be kept in the same suitable location as the log book.

22-2.1.8 Routine Maintenance. On a semiannual basis, vacuum clean the inside of cabinets and verify the tightness of all electrical connections. On an annual basis, check tightness of electrical connections and utilize infrared scanning or testing with a digital low resistance ohmmeter (refer to Section 18-12) to identify possible loose or corroded connections. Clean and retighten as required.

Periodically check all system alarms and indicating lights for proper operation. On a quarterly basis, visually inspect for signs of overheating and corrosion. Whenever additional loads are connected to the UPS, check the protective device coordination, calibration, and proper operation of the modified system.

Check all heating, ventilating, air conditioning, and humidity control systems for proper operation, and ensure that the flow of cooling air is not blocked by obstructions in front of the vents. Check for unusual sounds and odors because these signs may be the first indication of a potential malfunction.

The integrity of the grounding system must be maintained as required by Article 250 of the National Electrical Code. For separately derived systems, ascertain that the neutral is properly grounded.

The neutral output current should be measured during peak loads every three months or when new equipment is added to the system. Measurements should be taken using a true RMS type ammeter to verify that the neutral conductor ampacity is not exceeded. Excessive current readings could indicate the presence of harmonics.

22-2.1.9 Rectifier and Inverter (Static Systems). This equipment should be maintained in the manner prescribed for electronic equipment in Chapter 10. In many cases, a common enclosure houses the rectifier, inverter, and support battery charger sections of the UPS system.

On a semiannual basis, visually inspect the inverter for signs of leaking fluid from wave-forming capacitors; check the capacitors for swelling or discoloration. (*See 6-8.3.*)

Visually inspect the transformers and the heat sinks for signs of overheating.

22-2.1.10 Motor and Generator (Rotary Systems). The motor and generator should be maintained in accordance with the general procedures for maintaining rotating electrical equipment in Chapter 14.

22-2.1.11 UPS Modifications. It is extremely important that all modifications be reflected in the record drawings and other pertinent documentation (*see 22-2.1.7, UPS Recordkeeping*). Modifications to procedures should be recorded. Component failures and corrective action which impact the documentation, such as change in components, must be indicated.

The manufacturer should be contacted periodically (two year interval, maximum) for information on equipment upgrades and recommended revisions.

22-3 UPS Testing.

22-3.1 General.

22-3.1.1 UPS systems require periodic testing in order to determine if the system is functioning as designed. Each manufacturer provides, with the equipment, specifications delineating the stated equipment performance (i.e., voltage variation, balance, regulation, and harmonic distortion). Batteries can weaken, which will shorten the backup time of the particular manufacturer's specifications. Transfer operations might be generating transients or momentary outages that can create havoc in a computer system. The following recommendations are intended to identify problems and apprise the maintenance personnel of actual capabilities of the UPS system.

22-3.1.2 Testing should not be attempted unless those performing this work are completely familiar with the manufacturer's recommendations, specifications, tolerances, and safety precautions.

22-3.2 Preliminary Testing.

22-3.2.1 Prior to testing, record all operating parameters, such as frequency, voltage and current at the bypass switch, UPS input, UPS output, batteries, and at modules where applicable.

22-3.2.2 Tests should be performed with unit under load to ascertain the condition and reserve capability of the batteries. Refer to 6-8.4 for preparation of batteries prior to load testing of the system.

22-3.2.3 Perform an infrared scan of the batteries and UPS equipment. The scan should look specifically at the battery connections with ac input power disconnected and the battery supplying power to the load. Do not operate the unit under load for long periods of time with covers removed, because cooling may be inhibited and damage to the unit might result.

22-3.2.4 Correct any abnormalities that have been detected prior to proceeding with further testing.

22-4 System Tests.

22-4.1 General.

22-4.1.1 Certain system tests may be necessary to fully determine the operating condition of a UPS system. These tests should be performed when warranted by special circumstances, such as repeated failure of a system to pass routine maintenance checks. The tests also should be conducted on a two-year cycle or other periodic basis when the desired degree of reliability justifies the procedure. An independent testing company or the equipment manufacturer might be needed to conduct these tests, because of the complexity and the sophisticated test instruments required. The units should be placed under load by using external load banks during such tests.

22-4.1.2 All UPS tests require the batteries to be fully charged. (Some systems do not utilize battery backup.) Critical loads should be placed on isolation bypass, if available, or connected to another source.

22-4.1.3 Verify that all alarm and emergency shutdown functions are operating. Ascertain that the load transfers manually and automatically from UPS to bypass. Verify that all modules, when applicable, are functioning by load-testing each module individually prior to parallel load testing.

22-4.2 Special Tests. Take and record simultaneous input and output readings of voltage, current, and frequency. Remove and reapply the external power source to verify output stability.

Provide voltage and frequency recordings of UPS operation during transient response voltage tests; utilize a high speed recording device such as an oscillograph to document the following load tests:

Step load from 0 percent to 50 percent to 0 percent; 25 percent to 75 percent to 25 percent; 50 percent to 100 percent to 50 percent; 0 percent to 100 percent to 0 percent of UPS system rating.

Verify that the voltage regulation and frequency stability are within the manufacturer's specifications.

In accordance with the manufacturer's specifications, increase the load bank to greater than 100 percent system load, to ascertain that the system is within the manufacturer's ratings for input and output current overload rating.

Where applicable, remove UPS ac input power while the system is supplying 100 percent power to a load bank. Record the elapsed time until low battery voltage shutdown occurs, and compare this with specifications. Read and record voltage, current, and frequency during tests. Upon restoration of UPS input power, verify that the battery is recharging properly.

Correct any abnormalities, and ensure that the battery is fully recharged prior to returning the system to service.

Appendix A

Table A-2-2.2 Losses Associated with Electrical Failures Includes Electrical and Fire Damage*
1967 & 1968

Class of Equipment	*No. of Losses All Causes Incl. Unknown*	*Dollar Loss All Causes Incl. Unknown*	*Number Cause Unknown*	*Dollar Loss Due Cause Unknown*	*Number of Losses of Known Causes due to Defective Maintenance*	*Dollar Loss of Known Causes due to Defective Maintenance*
Generators	51	$ 367,690	20	$ 117,300	25	$ 233,000
Motors	420	1,627,530	109	560,000	256	924,000
Transformers	87	1,814,900	38	445,000	38	721,000
Circuit Breakers	27	199,700	11	117,000	14	74,600
Cables	73	580,010	21	140,000	45	406,000
Controllers	37	321,770	14	152,500	18	132,000
Switchgear	44	578,100	17	254,000	23	308,000
Switch Bds.	23	1,041,640	9	181,500	11	791,000
Switches Air & Oil	4	17,250	1	11,000	3	6,250
TOTAL	766	$6,548,590	240	$1,978,300	433	$3,595,850

*Statistics compiled by only one of the major insurance groups (Factory Mutual) that specialize in industrial fire and machinery insurance.

Appendix B Bibliography

This Appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.

B-1 Introduction.

B-1.1 This bibliography lists some of the more widely recognized sources of maintenance and testing information. There are many excellent text books by individual authors that are not listed because they are too numerous, and information on them is available from the various publishers.

B-1.2 For those who are interested in implementing an effective EPM program or improving an existing one, a suitable reference library should be readily available. Size of the plant and the extent of its maintenance and servicing operations will determine the desired publications for the reference library.

B-1.3. The need to use the manufacturer's service manuals and instructions furnished with specific equipment or apparatus has been previously mentioned and cannot be overemphasized. Additionally, there are many sources of helpful information on general and specific maintenance, troubleshooting, test methods, test instruments, and their use. Some of these are available without cost, but most entail a nominal charge. Publishers of technical and trade magazines are another important source of pertinent literature. Some can provide, without charge, reprints of specific articles, or, for a nominal fee, a compilation of reprints of articles on a particular subject.

American National Standards Institute

Part I of the *National Electrical Safety Code*, "Rules for the Installation and Maintenance of Electric Supply Stations and Equipment"—ANSI C2-1987.

Safety Requirements for the Lockout/Tagout of Energy Sources—ANSI Z244.1-1982.

American Petroleum Institute

Guide for Inspection of Refinery Equipment, Chapter XIV—Electrical Systems.

American Society for Testing and Materials

Rubber Insulating Gloves, Specifications for—ASTM D120-84.

Methods of Sampling Electrical Insulating Liquids—ASTM D923-86.

Rubber Insulating Blankets (without Fabric Reinforcement), Specifications for—ASTM D1048-81.

Rubber Insulating Hoods, Specifications for—ASTM D1049-83.

Rubber Insulating Line Hose, Specifications for—ASTM D1050-80.

Rubber Insulating Sleeves (Prof test 10,000 Volts, 3 Minutes), Specifications for—ASTM D1051-81.

Low-Voltage Rubber Insulating Gloves, Specifications for—ASTM D1700.

Nitrogen Gas as an Electrical Insulation Material, Specifications for—ASTM D1933-84.

Test Methods for Combustible Gases in Electrical Apparatus in the Field—ASTM D3284-84.

Methods for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography—ASTM D3612-85.

Crouse-Hinds

Suggestions for Installation and Maintenance of Electrical Equipment for Use in Hazardous Areas.

Department of the Army

Electrical Safety, Facilities Engineering U.S. Army TM-5-682 (June 1983).

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Operation, Maintenance and Repair of Auxiliary Generators U.S. Army TM-5-685.

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Handbook of Industrial Loss Prevention, Chapter 32.

Institute of Electrical and Electronics Engineers

Standard Techniques for High Voltage Testing—ANSI/IEEE 4-1978.

Recommended Practice for Testing Insulation Resistance of Rotating Machinery—ANSI/IEEE 43-1974 (Reaff.1985).

Guide for Insulation Maintenance of Large AC Rotating Machinery (1000 kVA and Larger)—ANSI/IEEE 56-1977 (Reaff.1982).

Guide for Field Testing Power Apparatus Insulation—IEEE 62-1978.

Guide for Operation and Maintenance of Turbine Generators—ANSI/IEEE 67-1972 (Reaff.1980).

Guide for Acceptance and Maintenance of Transformer Askarel in Equipment—IEEE 76-1974.

Guide for Safety in AC Substation Grounding—ANSI/IEEE 80-1986.

Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage—ANSI/IEEE 95-1977 (Reaff. 1982).

Graphic Symbols for Electrical and Electronics Diagrams—ANSI/IEEE 315-1975.

Guide for Making High Direct-Voltage Tests on Power Cable Systems in the Field—ANSI/IEEE 400-1980.

Guide for Insulation Maintenance for Rotating Electrical Machinery (5 HP to less than 10,000 HP)—ANSI/IEEE 432-1976 (Reaff.1982).

Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations—ANSI/IEEE 450-1980.

Design Test for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches and Accessories—ANSI/IEEE C37.410-1981.

Guide for Protective Relaying of Utility-Consumer Interconnections—ANSI/IEEE C37.95-1973 (Reaff.1980).

Guide for AC Motor Protection—ANSI/IEEE C37.96-1976 (Reaff.1981).

Recommended Practice for Installation, Application, Operation and Maintenance of Dry-Type General Purpose Distribution and Power Transformers—ANSI/IEEE C57.94-1982.

Guide for Acceptance and Maintenance of Insulating Oil in Equipment—ANSI/IEEE C57.106-1977.

Recommended Practice for Electrical Systems in Health Care Facilities—ANSI/IEEE 603-1986 (White Book).

Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities—ANSI/IEEE 739-1984 (Bronze Book).

Recommended Practice for Electric Power Systems in Commercial Buildings—ANSI/IEEE 241-1983 (Gray Book).

Recommended Practice for Grounding of Industrial and Commercial Power Systems—ANSI/IEEE 142-1982 (Green Book).

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Motor Applications and Maintenance Handbook, E. W. Boozer.

Preventative Maintenance of Electrical Equipment, C. I. Hubert.

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Application Guide for Ground-Fault Circuit Interrupters - 280-1984, see Section 7, "Field Test Devices" and Section 8, "Field Troubleshooting."

Instructions for the Handling, Installation, Operation, and Maintenance of Motor Control Centers - ICS 2.3-1983.

Instructions for the Safe Handling, Installation, Operation, and Maintenance of Deadfront Distribution Switchboards Rated 600 Volts or Less - PB 2.1-1986.

Instructions for the Safe Installation, Operation, and Maintenance of Panelboards Rated at 600 Volts or Less - PB 1.1-1986.

Maintenance of Motor Controllers After a Fault - ICS 2.2-1983.

Molded Case Circuit Breakers and Their Application - AB 3-1984, see Section 7 "Maintenance and Field Testing."

Procedures for Verifying Field Inspection and Performance Verification of Molded-Case Circuit Breakers - AB 2-1984.

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Safety Standard for Construction and Guide for Selection, Installation and Use of Electric Motors and Generators - ANSI/NEMA MG 2-1983, see Section 2.17.3, "Maintenance."

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Guidelines for Controlling Hazardous Energy During Maintenance and Servicing.

National Safety Council

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Electrical Inspections Illustrated - No. 129.46.

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National Safety Council (NSC), 444 N. Michigan Avenue, Chicago, IL 60611.

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Appendix C Suggestions for Inclusion in a Walk-through Inspection Checklist

This Appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.

These suggested items are directed toward minimizing the day-to-day electrical hazards. The list is not complete, nor do the items necessarily appear in order of importance. It is presented as a guide for the preparation of a checklist that should be developed for each plant. Because of the similarity to the plant fire prevention inspection, both inspections may be carried out by the same personnel.

Flexible Cords (Including Those on Appliances). Heater-type cords are required for portable heating appliances, such as toasters, grills, and coffee makers. Check condition for badly worn or frayed spots, splices (not permitted), improper type, current-carrying capacity too small.

Plugs and Connectors. Check for stray strands and loose terminals. Are they grounding type where required for specific appliances? Green conductor must be connected to grounding pin.

Extension Cords. Are they used in place of permanent wiring, of excessive length, of proper type? They should not pass through walls, partitions, or doors.

Multiple Current Taps. Are they used because of too few receptacles? Note particularly such areas as canteens, lunchrooms, and offices.

Appliances. Grills, toasters, and similar equipment should be permanently spaced from combustible material.

Heating Appliances. Where used with combustible material, such appliances generally require a signal light to indicate when "On."

Hot Water Heaters. Check for proper electrical protection. Manually operate the combination temperature- and pressure-relief valve to be sure it is free and the drainline is clear. Visually check setting.

Office Equipment. Check condition of flexible cords, plugs, and connectors. Look for excessive use of extension cords and multiple current taps.

Receptacle Outlets. Grounding-type receptables are generally required. Check each receptacle for continuity of grounding connection, using suitable test instrument. Are special receptacle configurations used for those supplying unusual voltages, frequencies, etc? Are they well-marked or identified? Note particularly missing faceplates, receptacles showing signs of severe arcing, loose mounting, etc.

Portable Equipment (Tools, Extension Lamps, and Extension Cords). In shop or tool room after each use, check for isolation between live parts and frame. Note condition of cord and plug. Is continuity maintained between frame and grounding pin of plug? The green conductor should connect only to the plug gounding pin. On lamps check condition of guards, shields, etc. See NFPA 70, *National Electrical Code*, for portable hand lamps; metal-shell, paper-lined lampholders for hand lamps are not permitted.

Lighting Fixtures. All lighting fixtures should be labeled and grounded. See NFPA 70, *National Electrical Code*, for connection of electric-discharge lighting fixtures. These may be connected by suitable, 3-conductor flexible cord where visible for its entire length and terminated at outer end in a grounding-type attachment plug or busway plug. No fixtures should be located close to highly combustible material. Note location of fixtures having burned out bulbs or tubes; where fixtures are heavily coated with dust, dirt, or other material; and where the reflectors are in need of cleaning.

Equipment Grounding. Where machinery or wiring enclosures are grounded through the conduit system, look for broken or loose connections at boxes and fittings, flexible connections, and exposed ground straps. Multiple bonding of conduit and other metallic enclosures to interior water piping systems including sprinkler systems, is sometimes used as a precaution where building vibration is severe, even though a separate equipment grounding conductor is run with the circuit conductors inside of the conduit.

Yard Transformer Stations. Note condition of transformers, fence, gates, and locks. Yard and equipment should be free of storage of combustible material, weeds, grass, vines, birds' nests, etc. Watch for indication of localized overheating indicated by conductor discoloration. Indication of excessive transformer temperature, pressure, or oil leakage should be noted.

Services. Visually check condition of weatherheads and weatherhoods to determine that they remain in good condition. Eliminate birds' and rats' nests, etc. At the same time, determine the apparent condition of lightning arresters, surge capacitors, grounding conductors, and grounds. Are switches safely and readily accessible?

Switchrooms and Motor Control Centers. Check to see that they are clean and used for no other purpose. They should be free of storage of any kind, especially combustible material. Ventilation equipment should be in working condition and unobstructed. Notice and promptly report any unusual noises or odors. Metering equipment should be checked for high or low voltage and current, and any indication of accidental grounding (ungrounded systems). Are switches and motor controllers properly identified as to function; are fire extinguishers in place, of suitable type, and charged?

Grouped Electrical Control Equipment (such as may be mounted on walls, etc.). Are they protected from physical damage and readily accessible? Are any equipment enclosures damaged or have missing or open covers? Are any live parts exposed? Report any condition preventing quick or ready access.

Enclosures of Electrical Parts (Motor Control Equipment, Junction Boxes, Switches, etc.). Are covers secured in place? Report location of broken or loose conduit, wiring gutters, etc. Missing dust caps should be replaced.

Hazardous (Classified) Location Equipment. All cover bolts should be in place and tight. Permanent markings should not be obstructed by paint. Examine joints between cover and case for signs of having been pried open in removing cover. This may have damaged the mating surfaces of the joints. Excessive accumulations of dust and dirt should be noted for removal from all enclosures, including motors, that also should be examined for obstructed ventilation. Note and report the use of nonexplosionproof electric equipment, including lighting that may have been installed in the hazardous (classified) location area.

Emergency Equipment.

(1) Exit lights should all be functioning properly.

(2) Emergency lights should all be in working condition. Periodic tests are recommended to be sure that they function when normal lighting is lost.

(3) Emergency power supplies such as batteries, engine-driven generators, etc., normally receive scheduled tests. Check records or periodic tests. Are fuel and cooling supplies for engine drives adequate? Are fire extinguishers in place, of proper type, and charged?

(4) Alarm systems, such as for fire, intrusion, smoke detection, sprinkler waterflow, and fire pumps, also receive periodic tests. Check records of these tests to be sure that all signals are properly transmitted and equipment is in good working condition.

Appendix D How to Instruct

This Appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.

D-1 Introduction. Training is basically a process for changing behavior. These behavioral changes are the product of new knowledge, reshaped attitudes, replaced skills, and newly acquired skills that express themselves, or become observable, as improved work techniques of the learner.

The trainer's function is to structure the instruction process in a manner that will make learning take place more effectively and in the shortest period of time.

D-2 Shortcomings of Learning by Trial and Error. Trial and error learning is learning at random. It is slow; it is costly in terms of time and mistakes. It also is costly because it involves so much "unlearning" of incorrect practices and "relearning" after the mistakes have been made.

Trial and error is the instructional process that continues to dominate industry. Its inefficiency can be illustrated by examining the case of the newly hired maintenance electrician assigned to instrument circuit repair work until "he gets the feel of the plant and 'learns' his way around."

> Assume that the assignment is to disconnect an instrument from the power source so that an instrument technician can change out a defective chart drive motor.
>
> Consistent with apparent good safety practice, and without consulting anyone, the electrician opened the switch that fed power to the entire instrument panel.
>
> Loss of control of the process resulted in major product spoilage.

This example illustrates what may happen any time people are put on jobs, simple or complex, without giving them organized instruction, either personally on the job or in groups off the job.

An even clearer illustration of the inefficiency of trial and error learning is the example of an inexperienced maintenance electrician who is charged with responsibility for motor trip-out troubleshooting, but who receives no formal instruction on this subject, which to him is unfamiliar.

His first attempts will include many blind alleys, such as going to the job location without the proper tools; a random inspection of the motor starter, the motor, and the driven load; or a random replacement of heater elements. As the number of his attempts to correct motor trip-outs increases, he may learn to avoid many of the blind alleys, and eventually he may come up with a logical (to him) sequence in steps that will shorten his job time.

If, on the other hand, he had been properly trained initially, the job could have been performed correctly, in the minimum of time because the maintenance electrician would have had full knowledge of the task and confidence in his own abilities to perform it. The further benefit of such training would have been less downtime, less material waste, and less chance of injury to himself and to other employees.

The justification for planned on- and off-the-job-training, therefore, is to get better results in the form of greater job knowledge, greater skills, and better job attitudes toward such factors as quality, cost, and productivity and in the shortest amount of time.

The job of the instructor, therefore, is to direct learning activities of trainees to avoid the blind alleys and mislearning that are inevitable with trial and error. This requires organized presentation.

D-3 Philosophy of Training.

In organizing a training program for a new learning situation, the major tasks involved are:

1. Selection of the experiences that will help the trainee learn what needs to be done.

2. Guiding of the trainee's efforts toward the proper learning objectives.

3. Applying the trainee's past experience.

4. Avoiding failures, frustrations, and loss of interest because the trainee does not perceive the relationships between what is presently being taught and future activity.

In discussing how the instructor can organize the presentation of subject material, assume, for the time being, that motivation has been provided and that the trainee recognizes the need for the training and has a desire to learn.

Whenever a skill is being taught, the instructor is not only presenting facts, he is also forming attitudes. For example, in learning how to make a relay adjustment, new information is being acquired. In addition, the trainee is forming attitudes and "mind sets" concerning the information presented as well as performance, precision standards, quality, safety, and equipment design. It is these attitudes and "mind sets" that will determine how the employee will approach or handle the job.

D-4 The Four-Step Method of Instruction.

A proven method of instruction is the "Four-Step Method." These four steps are:

Step One — Preparation

Step Two — Presentation

Step Three — Application

Step Four — Observation.

D-4.1 Step One: Preparation.

D-4.1.1 Preparation of Subject Matter.

A carefully laid out plan of action is a necessary operation for the presentation of new information and skills. Any mistakes made in presenting new material early in the teaching process will permanently confuse the trainee. To avoid teaching mistakes, the instructor should use a clearly worked out subject content outline and a step-by-step breakdown of the operations to be covered during instruction.

D-4.1.2 Subject Content Outline.

A carefully worked out subject content outline is important to both the beginning instructor and the expert. The new instructor may not deal fully with all the steps of the explanation. The expert may overlook steps that seem to be obvious. Therefore, both the new instructor and the expert should plan their presentations from the viewpoint of the trainee in order to instruct effectively.

D-4.1.3 Breakdown of the Subject Matter.

Instruction proceeds from the known to the unknown. It begins with the simple and proceeds to the complex.

Use of a step-by-step breakdown will ensure that the instruction will move progressively through a job, presenting it as it should be done from start to completion.

Instruction is accomplished by making certain that each new step is thoroughly explained and demonstrated in proper order and by making sure that the trainee understands what has been covered after each step.

The process of instruction is a natural process, with each step falling logically into place.

The problems encountered in instruction are generally due to the instructor's failure to take the time beforehand to carefully develop each explanation so that the entire topic makes sense.

When the presentation has been carefully broken down so that each unit being taught is clear and logical, the major obstacle to successful training has been overcome.

D-4.1.4 Preparation of Trainee.

(a) *Put the Trainee at Ease.*

The trainee needs to be receptive. Tensions need to be minimized. This can be achieved by creating an atmosphere of personal security. Introduce the trainees, demonstrate a friendly manner, get down to the business at hand promptly by explaining "what it's all about." Relieve the situation by anticipating the questions that normally are raised by the trainees, by clearly describing the objectives, by making the trainees aware of the advantages, and letting them know how the program will affect them personally.

(b) *Develop Favorable Attitudes.*

Attitude is a by-product of everything that occurs. The instructor will influence the shaping of the trainee's attitudes. Because attitude is a by-product, the development of a favorable attitude or outlook toward this program cannot be obtained by the simple process of talking about attitude directly. Instead, the instructor's responsibility is to do a good job of presenting the course, point out what is going to be covered, and how the program serves both the trainee's and the company's interest.

(c) *Find Out what the Trainees Already Know.*

Individual interest and receptivity of trainees to the subject material can be determined by briefly reviewing the backgrounds of members of the training group. This will avoid duplication and provide the instructor with information that will reveal the gap between what members of the group already know and the material to be presented.

(d) *Preview Material to Be Covered.*

Having determined background knowledge already known to the group, the instructor should brief the trainees on the ground to be covered. This briefing need not necessarily come in the same order as outlined here. The important consideration is that at some point before getting into the body of the lesson the instructor should tell the trainee what is going to be covered during the period.

Preliminary ground work is frequently looked upon as a "waste of time." But in training, it must be remembered that part of getting the job done is dealing first with the intangible assignment of psychologically preparing the trainee. Step One failure is the most common among new instructors. No lesson should be considered ready for presentation until specific measures to prepare the trainees have been developed.

D-4.2 Step Two: Presentation — Show and Tell.

The main points in "showing and telling" are:

D-4.2.1 Show How to Do the Job.

The instructor should demonstrate the operation carefully and accurately. If the operation is difficult, two or three demonstrations of the operation should be made. The instructor must not lose sight of the fact that *"showing" is very important in teaching.* The instructor must demonstrate, or "show how," before the trainee tries to do the job.

D-4.2.2 Tell and Explain the Operation.

After the class has seen the job demonstrated, the instructor should "tell how" the job is performed. It is important that the instructor let the class "learn by doing" *only after they have had the necessary instruction. The individual or class must never be put in the position of having to learn only by trial and error, or by simple observance.* In other words, the trainee must be *shown* and *told* exactly *what is expected and how to do it.* The details he should remember are pointed out to him.

D-4.2.3 Present Any Related Theory.

An electrical maintenance worker may actually carry out the sequence of actions required to do a job without knowing the basic principles that underlie the action. He may not understand why he does what he does; however, he will be a better technician if he does know why. This makes the difference between mechanical, machine-like, unmotivated performance and purposeful, participating workmanship.

D-4.2.4 Direct Attention of the Learner.

Showing and telling require that the instructor direct the attention of the trainees to the job. Describing an operation, showing a picture, or demonstrating an action is not enough. The important details must be pointed out and emphasized by directing the attention of the trainees to them. Attention may be directed in a number of ways.

One method of directing attention is to point out the item. Such emphasis will usually be coupled with "telling," with a question, or with a demonstration. Attention may also be directed by use of graphic devices, sketches, diagrams or board drawings, mobiles, and by the use of colors in printed material and on charts.

Board work can be emphasized by use of colored chalks. Changing the voice, slowing down the rate of talking, pausing, and the hundreds of devices of showmanship that dramatize a point are all effective means for directing attention of the learner.

D-4.3 Step Three: Application (Try-Out Performance).

Application provides a checkpoint on what has been learned. It is accomplished by having the class members "carry out" or "show back" how the job or operation is done. There are four major reasons for Step Three:

First, to repeat instructions; second, to show the trainees that the job can be done by following the instructions as given; third, to point out and to learn at which points the trainee may be experiencing difficulty; fourth, to indicate to the instructor whether or not the instructions given in Steps One and Two have been effective.

Performing the physical steps required to actually do a job will not test all the learning that should have been acquired. The instructor should check the trainees by additional means such as questioning, having them identify parts, asking them to summarize the steps verbally, and by stating reasons for functions.

D-4.3.1 Have the Trainee Explain and Perform Each Step.

To keep mistakes at a minimum, the instructor should have the trainee: first, tell *what* he is going to do; second, tell *how* he is going to do it; third, *do* the job. Telling "what" and "how" should come *in advance of doing it*. Have him carry out the necessary physical movements *after*, not before, the instructor is satisfied the trainee knows how to do it.

The instructor should have the trainee show how to do the job by the same method the instructor used in performing the operations. Because Step Three is the trainee's first opportunity to actually apply what has been taught, it is important to avoid incorrect practices from the start.

D-4.3.2 Have the Trainee Do Simpler Parts of the Operation First.

At this point, encouragement and success are important conditioners. Remember: early successes are beneficial to learning, to remembering, and to building interest in future learning.

Get the trainee into the job with as few errors as possible. As the most expert member of the group, it may be necessary for the instructor to assist the trainee by handling the more difficult parts the first time through.

D-4.3.3 Question the Trainee on Key Points.

One of the training hazards encountered in Step Three is the instructor's tendency to overlook slight omissions and details of the job that require explanation. *The instructor should never assume that the trainee understands what has been taught; he should verify it by questions.* If there are omissions of details in the trainee's demonstration and explanations, the instructor should raise questions to cover the details and have complete discussion of the points involved.

D-4.3.4 Make Corrections in a Positive and Impersonal Manner.

It should be remembered that the trainee is in the psychological position of trying to do what the instructor wants. The instructor should not lose sight of this and should not attempt to rush the learning or become impatient. In particular, the instructor must carefully consider each corrective step taken, and should praise the good work, even if it is very minor. Then the instructor should tell how some operations might have been performed more effectively. During the trainee's demonstration it will sometimes be better to permit minor mistakes to pass until the trainee has completed the explanation. Questions raised after the demonstration cause less interference and can be effectively used to "get across" the correct knowledge, methods, and points of view. When trainee mistakes are too frequent, the instructor will usually find the cause by going back to the instruction provided in Steps One and Two. *In other words, rather than attempt to explain mistakes made in Step Three presentations by trainees as being due to their failure to learn, the instructor's own handling of the trainees up to Step Three should be re-examined.* Usually when the frequency of errors in the presentation step is high, or when the same errors are being made by several trainees in the group, the cause can be traced to ineffective Step One or Step Two instruction.

In summary, the instructor should observe these basic rules to obtain better results and build more favorable work-related attitudes:

Make corrections in a *positive* manner.

Make corrections in an *impersonal* manner.

Focus attention on the *causes* of mistakes.

Help the trainees to *detect their own* mistakes and make their own critiques.

Correct with leading *questions*.

Get every trainee into the act...provide as much practice under direct observation as possible in the time allotted.

After members of the training group have shown they understand and can perform the operation, and after the instructor has been satisfied that a solid foundation of basic learning has been acquired, the group is ready to move to the final phase of instruction.

D-4.4 Step Four: Observation (Follow-up and Performance Testing).

Before considering the final step in the cycle of instruction let us briefly summarize the instruction process thus far:

Step	*Purpose*
One: Preparation	Organize
Two: Presentation	Motivate, show, and tell
Three: Application	Trainee demonstration

The purpose of Step Four is to prove that the trainees have learned by putting them in a work situation as nearly typical of the normal maintenance environment operations as possible.

Step Four provides an opportunity for the trainees to practice and gain experience in phases of the job that the instructor has covered. Job knowledge is reinforced and job skills are acquired only by doing. Without practice, skill cannot be developed.

These guidance factors are critical in Step Four:

D-4.4.1 Provide Close Follow-up on the Job.

When training is being provided simultaneously to a group, it becomes practically impossible for the instructor to do an adequate job of follow-up on each trainee. Despite this, *prompt follow-up is the most important aspect of Step Four.* Unless the trainees put the techniques they have been taught into practice, instruction has no purpose.

It takes application to learn techniques. It takes correct application to learn correct techniques. Trainees put on their own will often develop incorrect ways of doing their job. Follow-up is the only means tó prevent this. Responsibility for providing follow-up should definitely be assigned. Although it is common practice for the instructor to provide Step Four follow-up, there are definite advantages in sharing follow-up responsibilities with the supervisors of employees in training.

The training of maintenance electricians finds greater acceptance when there has been active line supervision involvement. One way that this can be achieved is by using engineering and maintenance supervision as a pilot group before the program is presented to the trainees. Another common practice is to use engineers or maintenance supervisors as instructors. Their use provides a variety of benefits, the most important being the bond built between the classroom and on-the-job performance. Also, inadequacies in training show up quickly, and on-the-job follow-up is efficiently implemented.

D-4.4.2 Provide Immediate Follow-up on the Job.

Heavy emphasis has been placed on follow-up. The timing of follow-up is crucial.

Unfortunately, the trainee sometimes views training as ending when the presentation phase is completed.

Follow-up is an easy function to put off. Its benefits are intangible, while daily maintenance demands are not. It is something the supervisor is not accustomed to, and other demands on his time get priority. Meanwhile, "wrong learning" multiplies. *Learning is learning, right or wrong.* Each error repeated is just that much more firmly instilled in the memory. This fact makes timing important. On-the-job follow-up should be phased out as performance demonstrates that correct methods and procedures have been learned and are being applied.

D-4.4.3 Maintain Performance Standards.

Performance expectations must aim high. There is no room for exceptions. If a quality standard is right, it must be observed when appraising trainee performance. If the standard is not right, it should be changed, not ignored.

Fault-free performance should be the training standard. Uniform results depend on uniform methods. High standards of equipment performance depend equally on high standards of equipment installation, operation, and maintenance.

Performance observation is the final filter in this developmental process. If the mesh is coarse, the product will be irregular. Trainees should not be "graduated" until they demonstrate capability using prescribed methods to obtain prescribed quality standards.

There may be times when many in a training group exhibit inadequate understanding of maintenance practices or quality requirements. Re-instruction of the entire group may be the most economical means for bringing about the improvement desired in these instances. Two items of correction technique have such important bearing on the success of retraining that we should repeat them at this time.

First, stress "what to do" instead of concentrating on "what was done incorrectly." Commend each correct detail. Focus on the step that is right. Pick up the operation at that point and supply the next "right" step. Then repeat each phase of the operation as it should be done. This is "positive reinforcement."

Second, use questions instead of making statements. Draw out correct information instead of supplying it again. The purpose should be to establish a learning situation in which the trainee is an active participant. Encourage trainees to analyze their own performance. The goal is maximum trainee involvement.

D-5 Summary: The Instruction Process in Brief.

D-5.1 Instruction is the process of teaching employees the knowledge, skills, and attitudes they need to do the jobs they are expected to do.

D-5.2 Instruction involves a variety of methods and techniques. The acquisition of knowledge, skills, and attitudes is the objective. How effectively instruction is organized and carried out determines the amount, rate, and permanence of new learning.

The industrial instructor's challenge is to develop ways to involve the trainee, and to discard the passive, lecture-based, nonparticipative methods inherited from the old-line techniques of academic institutions. Involvement is required if the trainee is to acquire new information and practical skills more effectively in the least amount of time. Equally important is the interest and desire to apply the new learning in the work situation.

D-5.3 Organized instruction is only effective when based on training methods that motivate the trainee.

D-5.3.1 Instruction should be presented so that it has practical meaning. The instructor should:

1. Present practical applications.
2. Use familiar experiences and words.
3. Get the trainee to participate in the instruction.
4. Use problem-solving discussions.
5. Relate class work to on-the-job situations.

D-5.3.2 Instruction should be purposeful; it should have a goal. To give purpose to training, the instructor should:

1. Make certain the reasons for the training are clear.
2. Emphasize the benefits to the individual.
3. Point out the practical applications of what is being taught.
4. Let the trainees know how they are doing.

D-5.4 Organize instructions to get active trainee participation. Participation can be increased by such methods as the following.

D-5.4.1 Use of models, mock-ups, graphs, charts, exhibits, and inspection tours of actual operations.

D-5.4.2 Using discussion and questions, having trainees prepare class materials, and encouraging trainee solutions of problems brought up in class.

D-5.4.3 Making specific assignments to trainees, providing individual practice, and having trainees research information.

D-5.5 The instruction process may be broken into four steps.

D-5.5.1 Step One: Prepare the Trainee.

(a) Develop motivation, reasons, advantages, and objectives.

(b) Get him or her interested in the training project.

(c) Become familiar with what trainees already know about the operation.

(d) State the job to be done; cover the whole job briefly.

D-5.5.2 Step Two: Presentation (Present the Operation).

(a) Tell, explain, show, and illustrate one step at a time, going from simple to complex.

(b) Stress each key point.

(c) Instruct clearly, completely and patiently.

D-5.5.3 Step Three: Application (Try-Out Performance).

(a) Have trainees perform operations step by step.

(b) Make certain that errors are corrected.

(c) Have each trainee perform the operation again while explaining each key point.

D-5.5.4 Step Four: Observation (Follow-up).

(a) Put trainees on their own.

(b) Designate to whom they should go for help.

(c) Establish definite arrangements for frequent checks.

(d) Encourage discussions and questions.

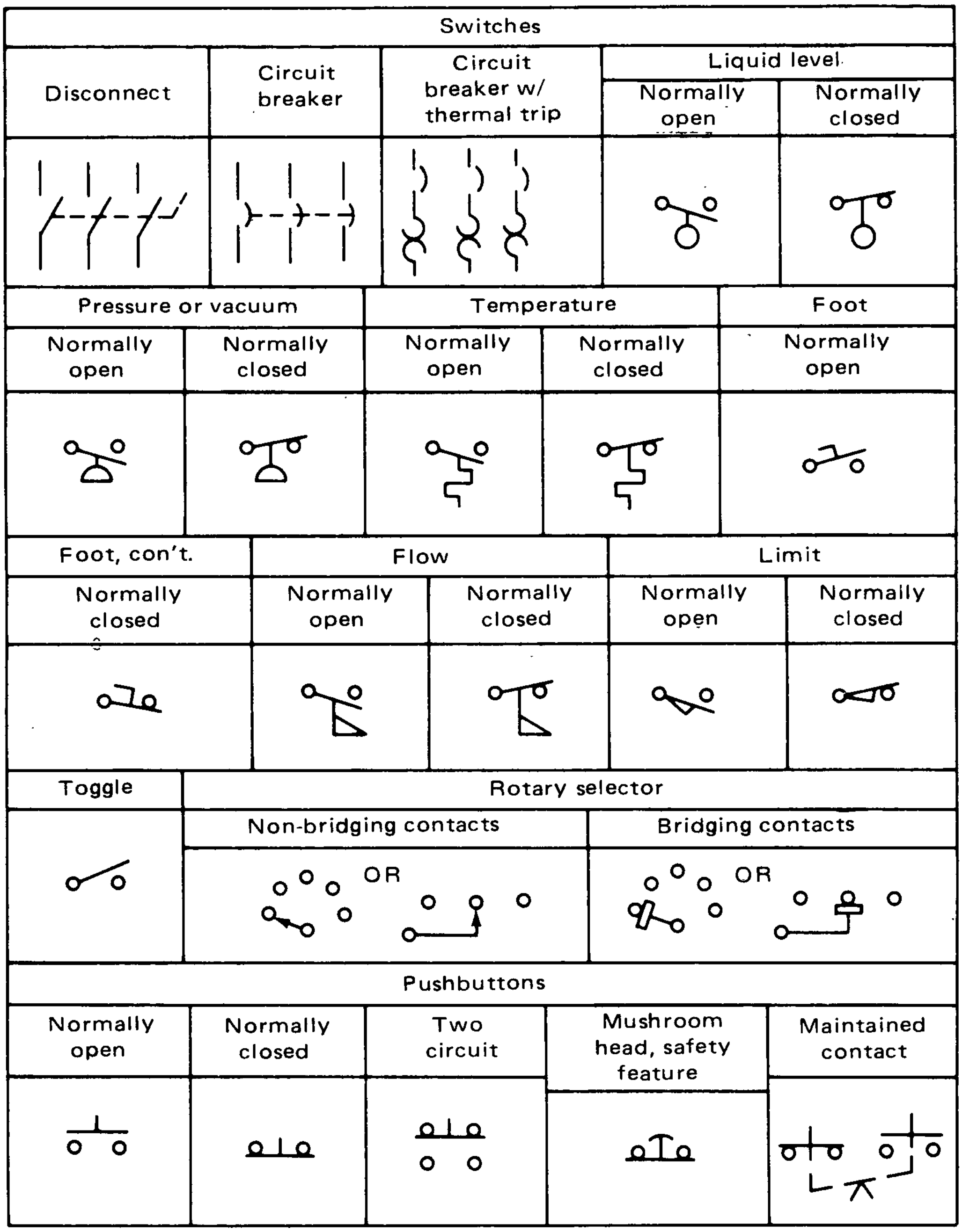
(e) Taper off follow-up.

Appendix E Symbols

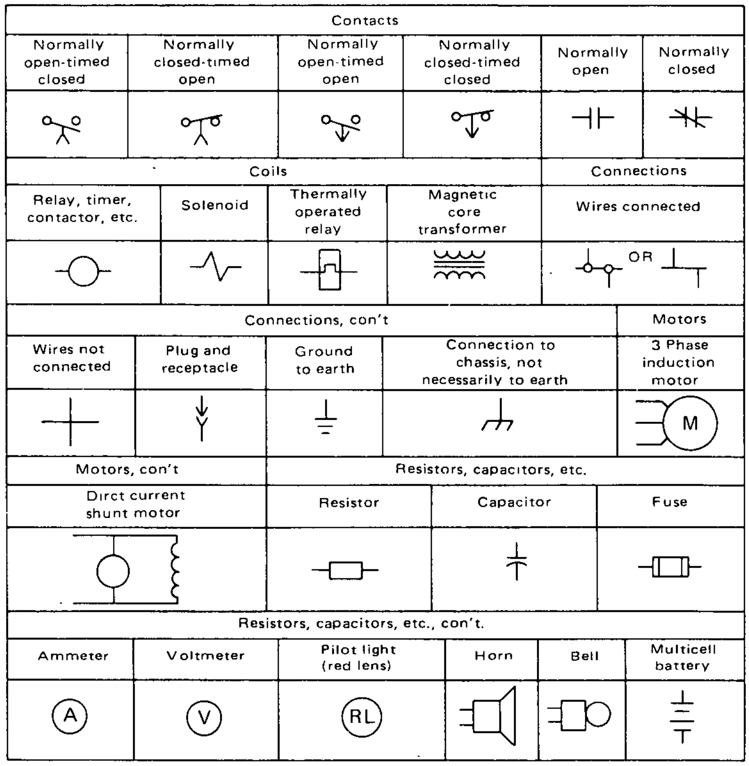
This Appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.

Appendix E-1 Some Typical Electrical Symbols

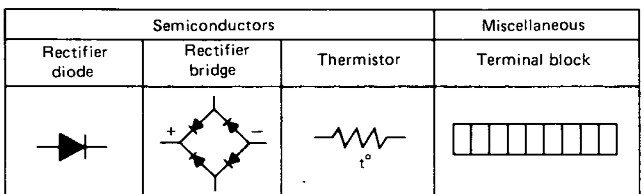
ANSI Y32.2—1970



Appendix E-2 Some Typical Electrical Symbols



Appendix E-3 Some Typical Electrical Symbols



Miscellaneous, con't.

Table of contact operation for control switch

Detached contacts shown elsewhere on diagram

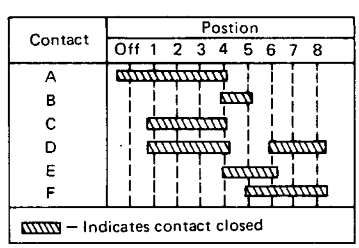
Contact	Position 1	Position 2	Position 3
A	X		
B		X	
C			X

X–Indicates contact closed

Miscellaneous, con't.

Table of contact operation for drum switch (sliding contact type)

Detached contacts shown elsewhere on diagram

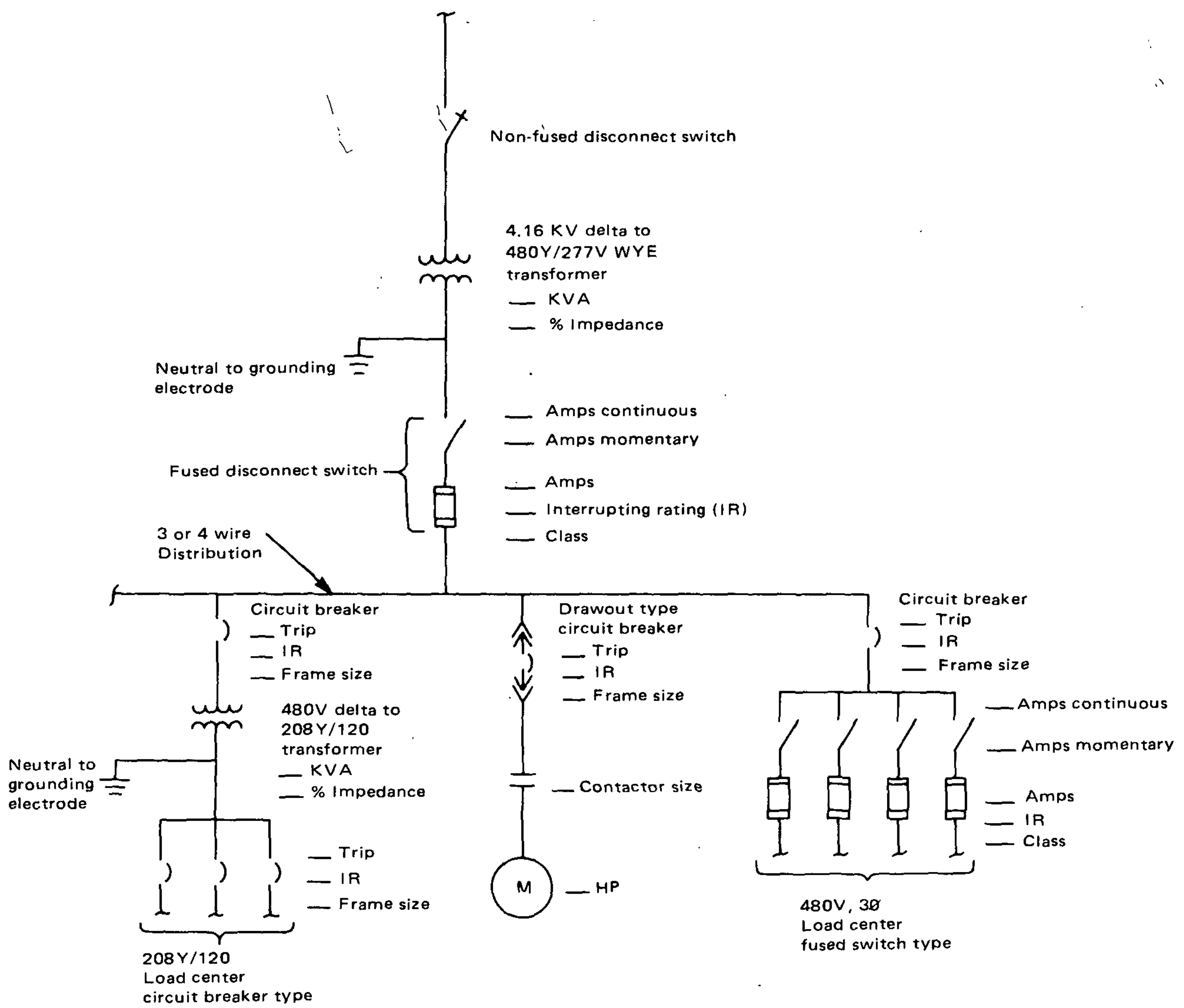


Appendix F Diagrams

This Appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.

Note: This is presented to show use of symbols and not to be construed to indicate recommendations.

Appendix F-1 Typical Use of Symbols in a Single-Line Power Distribution Program



Appendix F-2 Typical Wiring Diagrams

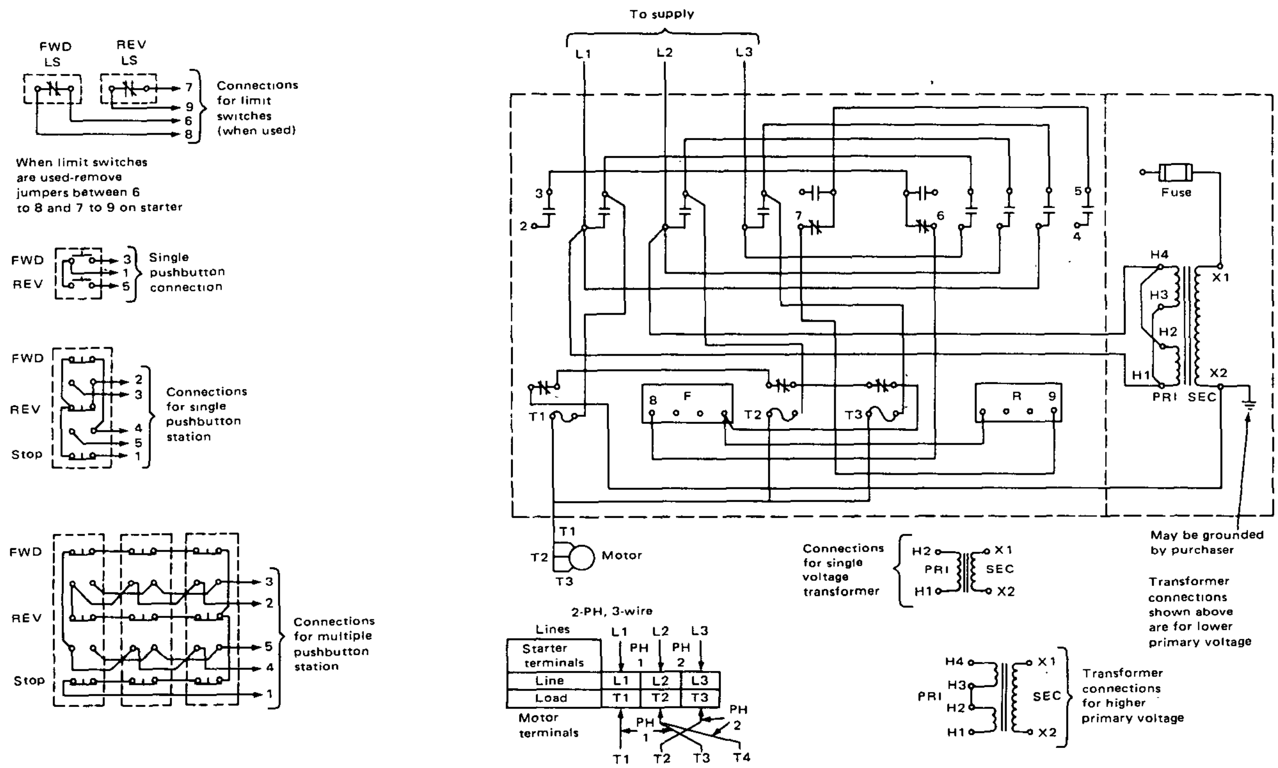
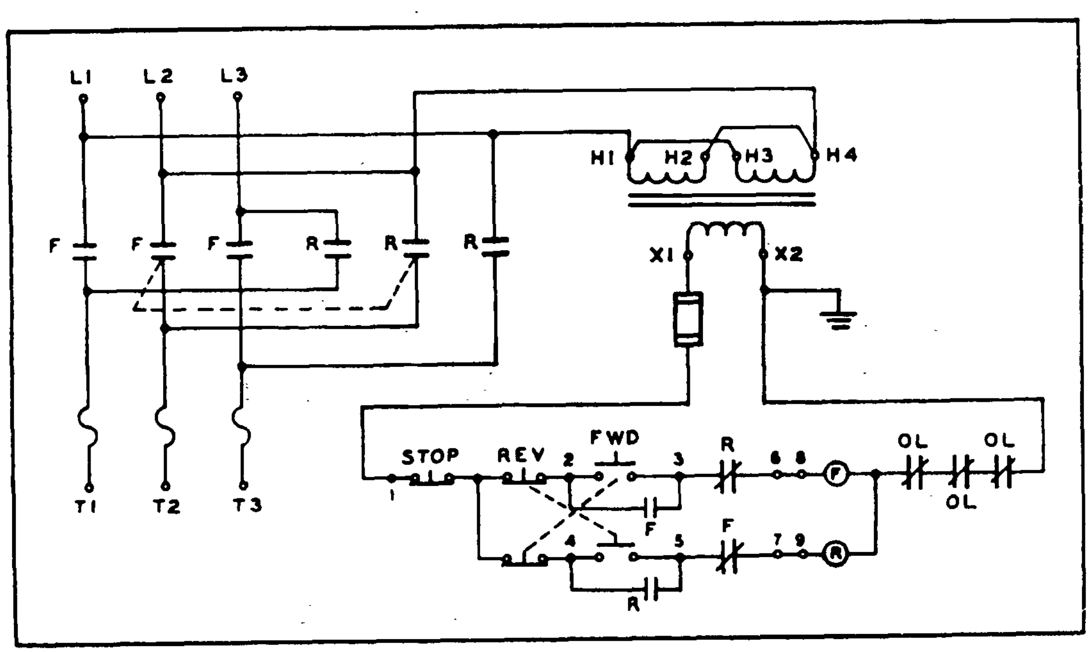


Diagram shows wiring for reversing starter with control transformer.

Appendix F-3 Typical Schematic Diagram



Power and control schematic for reversing starter with low-voltage remote pushbuttons. Forward, reverse, stop connections are shown.

Appendix G Forms

This Appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.

Appendix G-1 Typical Work Order Request Form

Work Order Request

WORK ORDER NO.	CRAFT

PLANT DEPARTMENT

DIRECTIONS TO REQUESTER: Complete Section I ONLY. Submit four copies to the Plant Department. Maintain last copy for your files. Prepare a separate request for each job. This request will be returned to you and becomes a work order only when approved and assigned a work order number by the Plant Department. Allow sufficient time for completion. Please TYPE your request.

I. TO BE COMPLETED BY REQUESTER: Date ..../........./.........

Summary of work request........

Location of work: Room(s) .... Building ....

Details of work request........

Typical work order request form consists of five parts — includes copies for plant department (or plant engineer), data processing, receiving stores, requester, and requester's department. Work to be done is spelled out in detail.

Special time requirement — Date needed......../......../........Indicate reason........

Department........Tel. Ext........ ☐ Plan attached ☐ Info. attached

Authorized signature........Title........Approval if required........

II. FOR PLANT DEPARTMENT USE ONLY: Date Received......../......../........

A. Your request has been ☐ Approved ☐ Disapproved ☐ Forwarded to .... for action. Use the assigned work order number when referring to this request.

B. Instructions:........

JOB ESTIMATES	Craft / Hours	Total Hours	Total Labor	Material	Grand Total
			$	$	$

Assigned to........Craft........ ☐ Day ☐ Night

Foreman —

C. Completed per Plant instructions? ☐ Yes ☐ No

Can recurrence be prevented? ☐ Yes ☐ No

If yes, indicate ....

ACTUAL HOURS USED	Tot. Reg.	Tot. O/T	Tot. Equiv. Hrs.

Requester —

Completed per your request? ☐ Yes ☐ No

Plant and Requester note variations........

Date........Foreman's Signature........Requester's Signature........

III. FOR DATA PROCESSING USE ONLY

Dept.	Bldg.	Class	Category	Cause	Pay	O/T $

Total Labor $	+	Total Material $	=	Total $

Work Description (Alphabetic)

WORK ORDER NO. CRAFT

PLANT DEPARTMENT

Appendix G-2
Air Circuit Breaker — Inspection Record

Plant ______________________ Date ______________________

Location ______________________ Serial No. __________

MFR. ______________________ Type or Model ______________________

Draw out ☐ Non-draw out ☐ Switch board ☐ Metalclad ☐

Rating: Volts __________ Amps __________ Interrupting Amps ______________

Operation: Manual ☐ Electrical ☐ Remote Control ☐

Volts close ________ AC ☐ DC ☐ Volts trip ________ AC ☐ DC ☐

Protective Devices: Induction Relays ☐ Direct Trips ☐

CL Fuses ☐ TD Setting ________ INST. Setting ________

ANNUAL INSPECTION

DATE										
INSPECTOR'S INITIALS										
	AUX.	MAIN	AUX.	MAIN	AUX.	MAIN	AUX.	MAIN	AUX.	MAIN
CONTACT CONDITION										
Good – Surface Smooth										
Fair – Minor Burns										
Poor – Burned & Pitted										
CONTACT CHECK										
Pressure (Good, Weak, Bad)										
Alignment (Good, Bad)										
DRAWOUT CONTACTS										
Pressure (Good, Weak, Bad)										
Alignment (Good, Bad)										
Lubricate (Must Do – Use A No-Oxide Lubricant By Mfr.										
ARCING ASSEMBLIES										
Clean and Check the Arc Splitting Plates										
Surface Conditions										
BUSHINGS										
Clean and Check Surface Condition										

DATE					
INSPECTOR'S INITIALS					
OPERATING MECHANISMS CHECKS					
Positive Close & Trip					
Bushing & Pin Wear					
Set Screws & Keepers					
Protective Devices					
Lubricate Wear Points					
Clean Pots and Replace Oil with Eqpt. Mfrs. Recommended Oil					
INSULATION CONDITION					
Loose Connections					
Discolored Areas					
Corona Tracking					
Clean Surfaces					
INSULATION TESTS					
Phase to Phase (Megohm)					
Phase to Ground (Megohm)					
TEST OPERATION					
Close & Trip					
Counter Reading (No. of Ops.)					
ELECTRICAL LOAD					
Peak Indicated Amps					

Remarks: (Record action taken when indicated by Inspection or Tests)

____

____

ther Repairs Recommended:

____

____

Appendix G-3
Air Circuit Breaker Test and Inspection Report

Customer ______ Date ______ Work Order No. ______

Address ______ Air Temp. ______ Rel. Humidity ______

Breaker Owner/User ______ Date Last Inspection ______

Address ______ Last Inspection Report No. ______

Equipment Location ______

Owner Identification ______

BREAKER DATA:

Manufacturer ______ Voltage ______ Type ______ Amps. ______ Int. Rating ______

Serial No. ______ Type Oper. Mech. ______ Age ______ Other N.P. Data ______

TEST DATA:

	Tank 1	Tank 2	Tank 3
Ins. Res., ______ kv, Megohms			
Contact Resistance, Microhms			
Closing Speed/Opening Speed			
Reference, P.F. Test Sheet No.			

ADJUSTMENTS:

	Mfr's. Rec.	As Found	As Left
Arcing Contact Wipe			
Main Contact Gap			
Main Contact Wipe			
Latch Wipe			
Latch Clearance			
Contact Travel			
Prop Clearance			
Stop Clearance			

INSPECTION AND MAINTENANCE:

	Insp.	Dirty	Cleaned / Lubed.	See Remarks
Overall Cleanliness				
Insulating Members				
Mech. Connections				
Structural Members				
Cubicle				
Pri. Contact Fingers				
Shutter Mech.				
Relays				
Auxiliary Devices				
Racking Device				
Arc Chutes				
Blow Out Coil				
Puffers				
Liner				
Arc Runners				
Main Contacts				
Cubicle Wiring				
Breaker Wiring				
Heaters				
Panel Lights				
Bearings				
Contact Sequence				
Ground Connection				
Counter Reading				

REMARKS: ______

______

______

______

______

Inspection & Test by: ______ Equipment Used: ______ Sheet No. ______

Appendix G-4
Low-Voltage Circuit Breaker Five Year Tests Form

Plant ______________________ Date ____________

Substation ____________ Feeder ____________ Load Reading ____________

BREAKER DATA

Mfr. ____________ Type ____________ Serial No. ____________

Trip Coil Rating ________amps Characteristic ________ Mfr's. Time Curve ______

Trip Devices: Long Time Delay ☐ Short Time Delay ☐ Instantaneous Trip ☐

Time Delay Type: Oil Sucker Dashpot ☐ Air Bellows ☐ Air Orifice ☐ Oil Orifice ☐

Other ☐

Settings:

LT Delay — Amps _____ Adjustable Range _____ Time Adjustable? Yes ☐ No ☐

ST Delay — Amps _____ Adjustable Range _____ Time Adjustable? Yes ☐ No ☐

Instantaneous Trip — Amps __________ Adjustable? Yes ☐ No ☐

TEST DATA

Date of Test / Inspector's Initials		LEFT POLE	CENTER POLE	RIGHT POLE	TIME RANGE FROM CURVE
AS FOUND TEST (Trip Time in Seconds) % Pickup ____ Amps ____					
TIME DELAY MINIMUM PICKUP (Nullify Time Delay)	(As Found - Amps)				
	(Adjusted - Amps)				
TIME DELAY TESTS (Trip Time in Seconds) % Pickup Amps Long Time					
____ ____					
____ ____					
Short Time					
____ ____					
____ ____					
RESETTABLE DELAY (___ % for ___sec)	(Satisfactory)				
	(Tripped)				
INSTANTANEOUS TRIP	(As Found - Amps)				
	(Adjusted - Amps)				

Remarks: (Record unusual conditions, corrections, needed repairs, etc. Use separate form to record annual breaker inspection details.)

____

____

____

Appendix G-5
Electrical Switchgear — Associated Equipment
Inspection Record

Plant ______________________ Date ______________

Location ______________________ Serial No. __________

MFR. ______________________ Year Installed ______________

Rating: Volts ______________ Bus Capacity Amps ______________

Type: Switchboard ☐ Indoor Metalclad ☐ Outdoor Metalclad ☐

ANNUAL INSPECTION (Disregard items which do not apply)

DATE					
INSPECTOR'S INITIALS					
SWITCHBOARDS					
Clean					
Check Wiring					
Inspect Panel Insulation					
EXPOSED BUS & CONNECTIONS					
Clean and Check Porcelain Insulators for Cracks or Chips					
Check & Tighten Connections					
Inspect Potheads for Leaks					
Check for Enviromental Hazards					
Test Insulation (Megohms)					
METALCLAD ENCLOSURES					
Clean					
Check for Openings which Permit Dirt, Moisture & Rodent Entrance – Repair					
Check Hardware for Rust or Corrosion					
Paint Condition					
Check Heaters & Ventilators					
METALCLAD BUS & CONNECTIONS					
Clean Insulators & Supports					
Check & Tighten Connections					
Check for Corona Tracking					
Inspect Potheads for Leaks					
Test Insulation (Megohms)					

DATE					
INSPECTOR'S INITIALS					
DISCONNECT SWITCHES					
Check Contact Surfaces					
Check Insulation Condition					
Lubricate per Mfr's. Instructions					
Test Operate					
FUSES & HOLDERS					
Check Contact Surfaces					
Lubricate per Mfr's. Instructions					
METERS & INSTRUMENTS					
Check Operation					
Test Meters per Eng. Std.					
Test Relays per mfr's instructions					
INTERLOCKS & SAFETY					
Check for Proper Operation					
Check Lightning Arresters					
Check Ground Detectors					
Check Eqpt. Grounds					
STATION BATTERY					
Inspect to Confirm that Periodic Routine Maintenance is Performed					

Remarks: (Record action when indicated by Inspection or Tests)

____

____

Recommendations:

____

____

____

Appendix G-6
Transformer — Dry Type — Inspection Record

Plant ______________________ Date ______________

Location ______________________ Serial No. ______________

Year Purchased ____________ Year Installed ____________ Mfr. ______________

KVA ____________ Voltage ____________ Impedance ______________

Phase ____________ Taps ______________

Cooling system: Room Vent Fan ☐ Trans. Fans ☐ Gravity ☐

ANNUAL INSPECTION

DATE						DATE					
INSPECTOR'S INITIALS						INSPECTOR'S INITIALS					
ELECTRICAL LOAD						BUSHINGS					
						Cracks or Chips					
						Cleanliness					
SECONDARY VOLTAGE						EQUIPMENT GROUND					
No Load Volts						Check Connections					
Full Load Volts						Measured V					
						Resistance					
DUST ON WINDINGS						TEMPERATURE ALARMS AND INDICATORS					
Minor Collection						Operation					
Major Collection						Accuracy					
Cleaned						CASE EXTERIOR					
CONNECTIONS						Covers Intact					
Checked						Paint Condition					
Tightened						LIGHTING ARRESTERS					
COOLING SYSTEMS						Check Connections					
Fan Operation						Check Bushings					
Filter Cleanliness											
System Adequate											

COMPLETE INTERNAL INSPECTION

Report of Conditions Found:

Cooling System ______________________

Coil Insulation ______________________

Other ______________________

Description of Work Performed: ______________________

____

____

Other Repairs Recommended: ______________________

____

____

Shop or Contractor: ______________________ Cost: ____

Appendix G-7
Transformer — Liquid Filled — Inspection Record

Plant ______________________ Date ______________

Location ______________________ Serial No. ______________

Year Purchased __________ Year Installed __________ Mfr. __________

KVA ______________ Voltage ______________ Taps __________

Check Type: Free Breathing ☐ Conservator ☐ Sealed ☐ Fan Cooled ☐

Phase ______________ Weight ______________ Impedance __________

Insulating Fluid: Type ______________ Gallons ______________

ANNUAL INSPECTION

DATE					
INSPECTOR'S INITIALS					
TANK – LIQUID LEVEL					
Normal					
Below					
Added Fluid					
ENTRANCE COMPARTMENT LIQUID LEVEL					
Normal					
Below					
Added Fluid					
ELECTRICAL LOAD					
Peak Amps					
SECONDARY VOLTAGE					
Full Load					
No Load					
GASKETS & CASE EXTERIOR					
Liquid Leaks					
Paint Condition					

DATE					
INSPECTOR'S INITIALS					
EXPOSED BUSHINGS					
Cracks or Chips					
Cleanliness					
EQUIPMENT GROUND CONNECTION					
Good					
Questionable					
Tested					
TEMP INDICATOR					
Highest Reading					
Reset Pointer					
PRESSURE–VACUUM INDICATOR					
Pressure					
Vacuum					
VENTILATORS, DRYERS, GAUGES, FILTERS & OTHER AUXILIARIES					
Operation OK					
Maint. Req'd.					

Remarks: (Record action when Inspection data or tests are out of limits, etc.)

____

____

Report of Conditions Found: ______________________________

Description of Work Performed: ______________________________

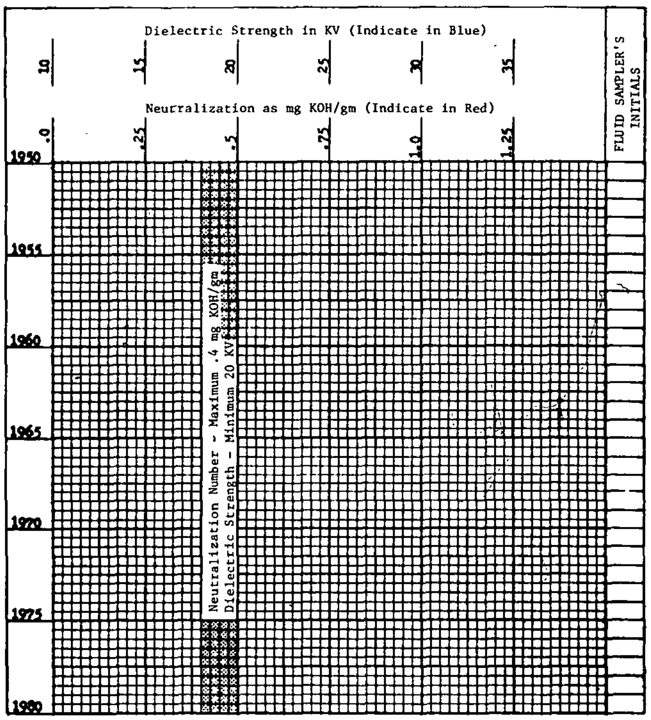
Other Repairs Recommended: ______________________________

Shop or Contractor: ______________________ Cost: ______________

Appendix G-8
Transformer Fluid Test — Oil

PLANT ______________________ DATE ______________

MANUFACTURER'S S/N ______________

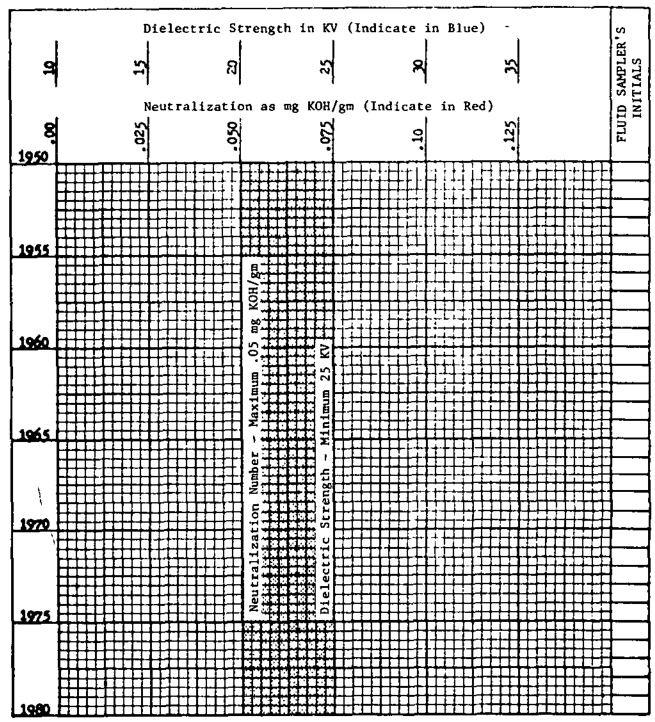


Note: Readings that plot in the shaded zone must be reported immediately to the Engineering Division, Electrical Section.

Appendix G-9
Transformer Fluid Test — Askarel

PLANT ______________________ DATE ______________

MANUFACTURER'S S/N ______________



Note: Readings that plot in the shaded zone must be reported immediately to the Engineering Division, Electrical Section.

Appendix G-10
Transformer Insulation Resistance Record

Plant ______________________ Date ______________

Scope: Power transformers of 150 KVA and greater capacity with primary voltage of 2300 volts or higher. Direct reading – recorded and plotted.

Transformer Serial No. ____________ Phase ____________

Location ____________ Instrument Used ____________

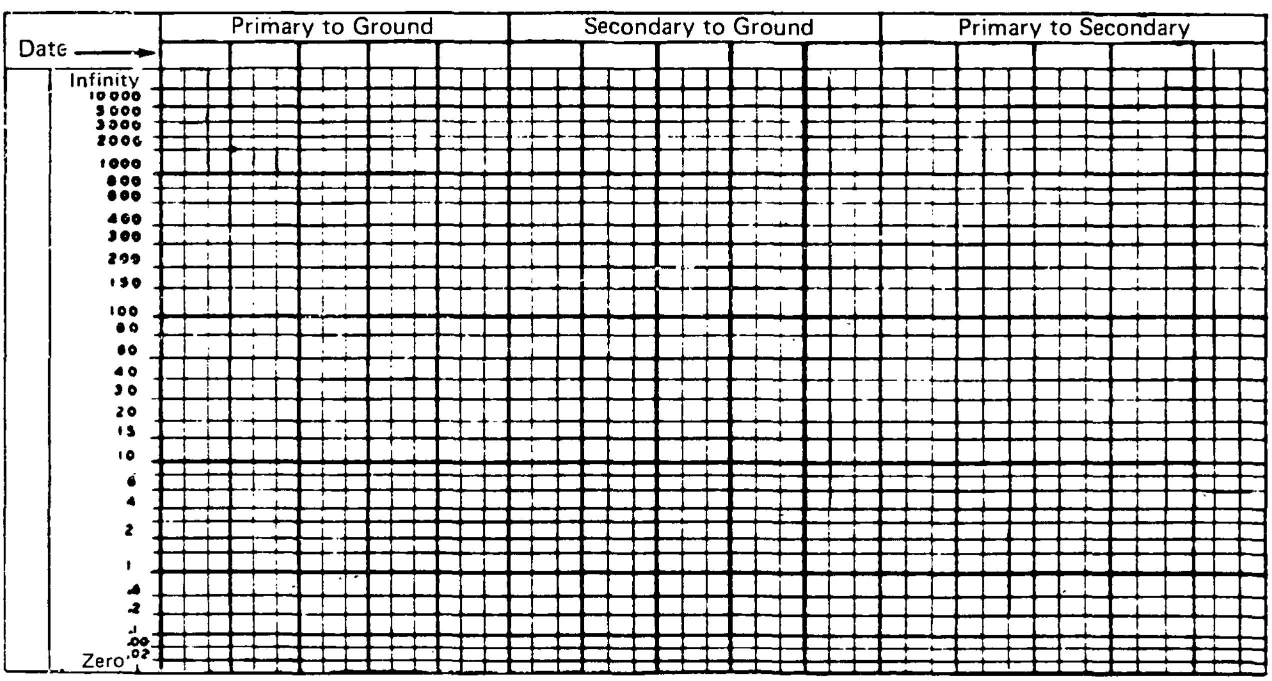
Equipment Included in Test: ______________________

____

____

II*	Date	Pri. to Grd.	Sec. to Grd.	Pri. to Sec.	Internal Temp.	Ambient Temp.

*Inspector's Initials



Remarks:

Appendix G-11
Battery Record

No. Calls ____________ Type ____________ Service ____________ Bldg. ____________

Note. Correct specific gravity readings for temperature.

Weekly Pilot Cell Readings: Cell No. ______

Date	Pilot Cell Sp. Gr.	Pilot Cell Temp.	Buss Volts	Water Clean	Check Charger

Remarks: ____________

Quarterly Cell Readings: Date ______

Cell	Specific Gravity	Volts	Cell	Specific Gravity	Volts
1			31		
2			32		
3			33		
4			34		
5			35		
6			36		
7			37		
8			38		
9			39		
10			40		
11			41		
12			42		
13			43		
14			44		
15			45		
16			46		
17			47		
18			48		
19			49		
20			50		
21			51		
22			52		
23			53		
24			54		
25			55		
26			56		
27			57		
28			58		
29			59		
30			60		

Buss Volts ________ Current ________

Battery Room Condition ________

Cell Temps. 1 ________ 15 ________

30 ________ 45 ________ 60 ________

Appendix G-12
Insulation Resistance — Dieletric Absorption Test Sheet Power Cable

TEST NO. ________

________ COMPANY DATE ________

________ LOCATION TIME ________

CIRCUIT	CIRCUIT LENGTH	AERIAL ☐ DUCT ☐ BURIED ☐	
NUMBER OF CONDUCTORS	CONDUCTOR SIZE	AWG M.C.M.	BELTED ☐ SHIELDED ☐
INSULATING MATERIAL	INSULATION THICKNESS	VOLTAGE RATING	AGE
POTHEAD OR TERMINAL TYPE	LOCATION INDOORS ☐ OUTDOORS ☐		
NUMBER AND TYPE OF JOINTS			
RECENT OPERATING HISTORY			
	MFR.		
STATE IF POTHEADS OR TERMINALS WERE GUARDED DURING TEST			
LIST ASSOCIATED EQUIPMENT INCLUDED IN TEST			
MISC INFORMATION			

TEST DATA - MEGOHMS

PART TESTED				
GROUNDING TIME				
TEST VOLTAGE				
TEST CONNECTIONS	TO LINE	TO LINE	TO LINE	TO LINE
	TO EARTH	TO EARTH	TO EARTH	TO EARTH
	TO GUARD	TO GUARD	TO GUARD	TO GUARD
¼ MIN.				
½ "				
¾ "				
1 "				
2 "				
3 "				
4 "				
5 "				
6 "				
7 "				
8 "				
9 "				
10 "				
10/1 MIN RATIO				

TEST MADE	HOURS DAYS	AFTER SHUTDOWN
DRY-BULB TEMP		°F
WET-BULB TEMP.		°F
DEW POINT		°F
RELATIVE HUMIDITY		%
ABSOLUTE HUMIDITY		GR./#
EQUIPMENT TEMP.		°F(C)
HOW OBTAINED		
"MEGGER" INST :—		
SERIAL #		
RANGE		
VOLTAGE		

REMARKS ________

TESTED BY ________

Appendix G-13
Cable Test Sheet

COMPANY ______________________ DATE ____________ JOB NO. ________

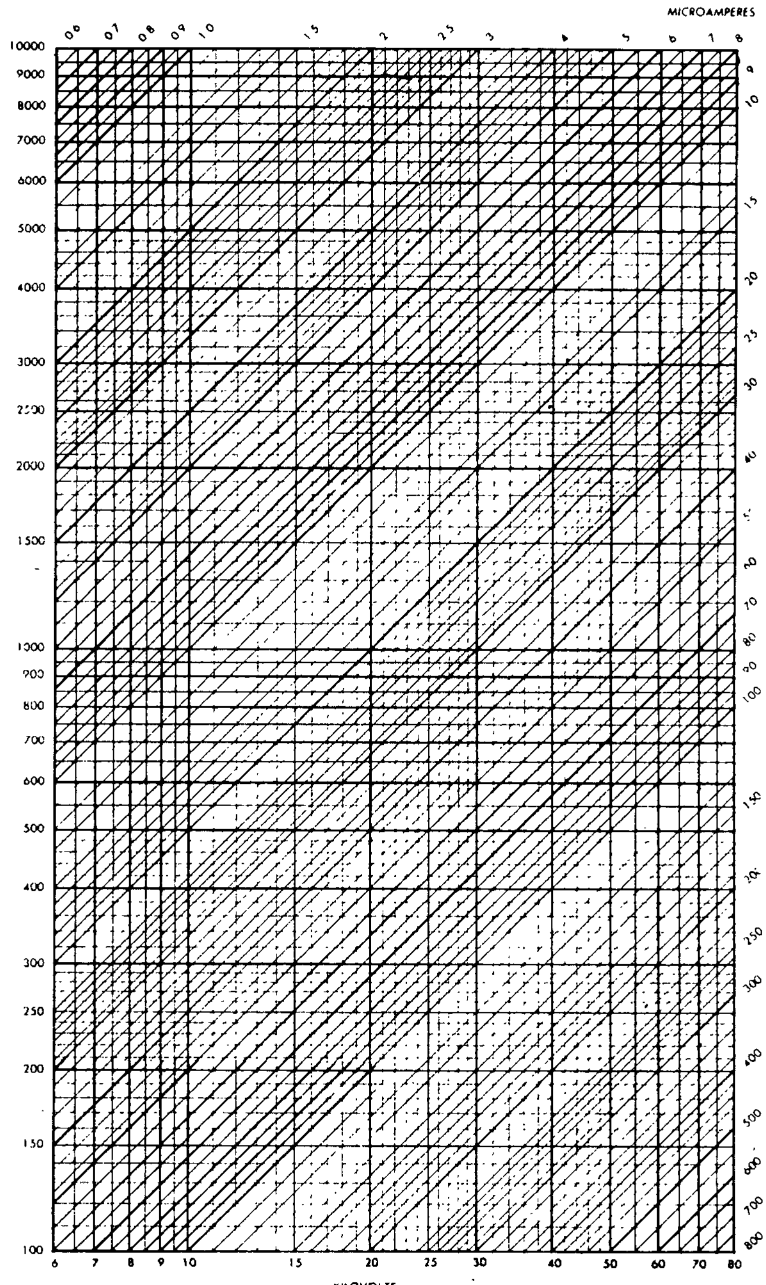
TEST LOCATION ______________________ CIRCUIT ______________________ AIR TEMP. ________ °C % HUM ________

TYPE TEST: ACCEPTANCE ☐, PERIODIC ☐, SPECIAL ☐ DATE LAST TEST ____________ SHEET NO. ____________ WEATHER ____________

CABLE MFR.	
RATED Kv	(GND., UNGND.)
OPER. Kv	(GND., UNGND.)
LENGTH	
AGE	
NO. COND.	
SIZE	
INSUL. MATERIAL	
INSUL. THICKNESS	
INSUL. TYPE	
COVERING	
INSTALLED IN	
FACTORY TEST Kv	
% FACTORY TEST Kv	
MAX. TEST Kv	
VOLTMETER Kv	

TIME MIN.	VOLTS Kv	LEAKAGE CURRENT-MICROAMPS Φ1 - ⊙	Φ2 - △	Φ3 - ⊡

INSULATION RESISTANCE TEST ONE MINUTE @ 2.5 Kv - 1000 MEGOHMS			
Φ TO GND.			
Φ1 TO Φ	—		
Φ2 TO Φ	—	—	



AUTHORIZATION OF MAX. TEST Kv AND VERIFYING VOLTMETER Kv

____
SIGNATURE

REMARKS ______________________

____

____

____

TEST SET NO. ____________ TESTED BY ______________________ SHEET NO. ____________

Appendix G-14
Insulation Resistance Test Record

Date ____________________

Scope: Dielectric Absorption without Temperature Correction

Apparatus ______________ Equipment Temp. ______________ Ambient Temp. _____

Instrument Used ______________________ Polarization Index No. ________________

Condition 10:1 Min. Ratio

Dangerous -------Less than 1

Poor ------------Less than 1.5

Questionable ----1.5 to 2

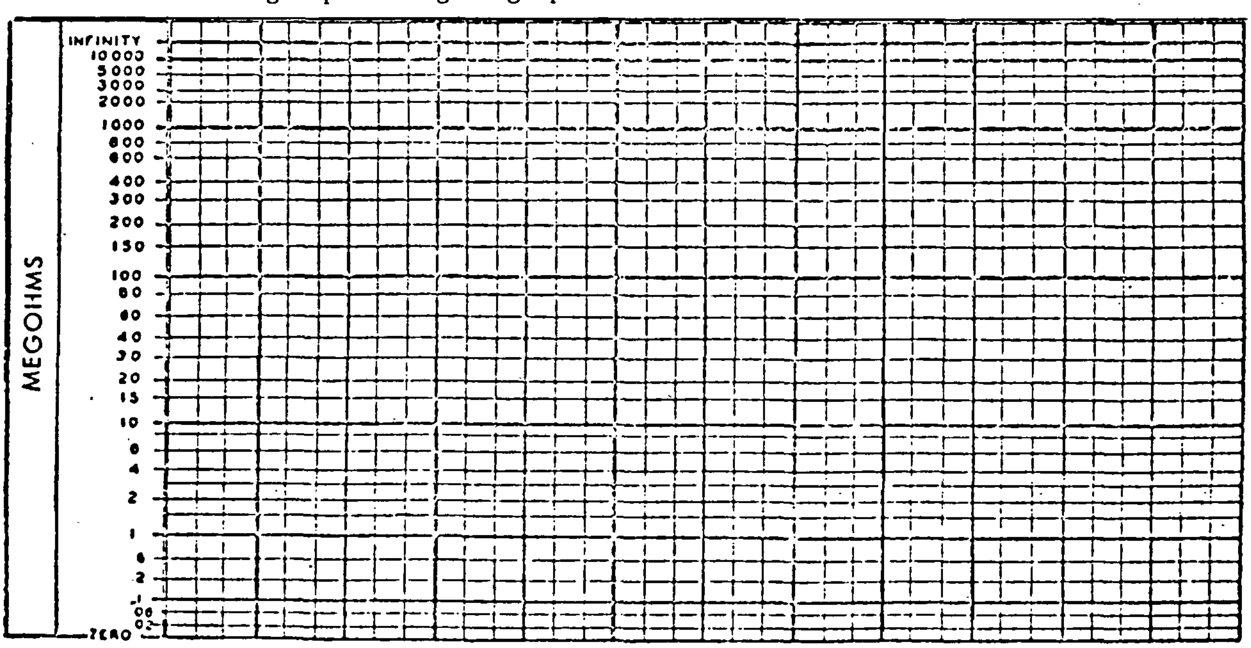
Fair --------2 to 3

Good --------3 to 4

Excellent ---Above 4

Time in Minutes		.25	.50	1	2	3	4	5	6	7	8	9	10
To Ground	Phase 1												
	Phase 2												
	Phase 3												
Between Phases	Phase 1–2												
	Phase 2–3												
	Phase 3–1												

-Plot the lowest group reading on graph



Tested by ____________________

Appendix G-15
Insulation Resistance Test Record
Rotating Machinery

References

IEEE Publication No. 43

Scope

Dielectric Absorption – Temperature Corrected

AC Machines 1000 KVA or more
DC Machines 100 KW or more

Date ______________________

Apparatus ______________________ Voltage __________ Rating __________

Test Conditions:

List Associated Equipment Included in Test ______________________

Winding Grounding Time __________ Test Made __________ Hours After Shutdown

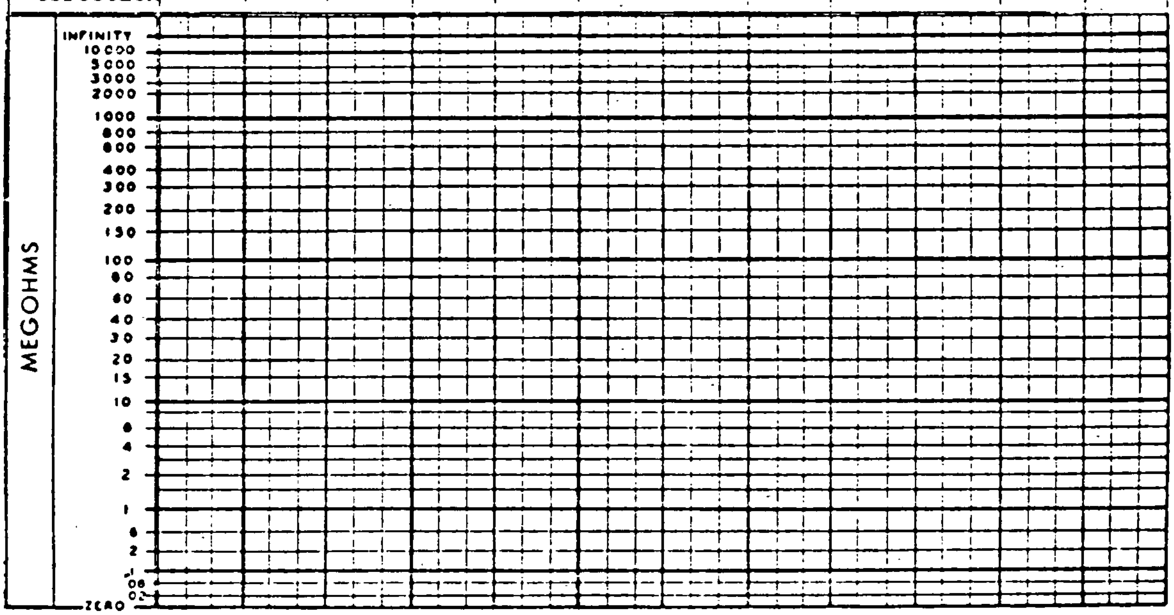
Ambient Temperature ________ °F Relative Humidity ________ % Weather ________

Equipment Temperature __________ How Obtained __________

Instrument __________ Range __________ Voltage __________

Test Data:

Minutes	.25	.5	1	2	3	4	5	6	7	8	9	10
Reading												
Correction												



Polarization No. (10/1 min. Ratio) __________ Tested by __________

Remarks:

Appendix H NEMA Configurations

This Appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.

Appendix H-1

NEMA CONFIGURATIONS FOR GENERAL-PURPOSE NONLOCKING PLUGS AND RECEPTACLES

		15 AMPERE		20 AMPERE		30 AMPERE		50 AMPERE		60 AMPERE	
		RECEPTACLE	PLUG	RECEPTACLE	PLUG	RECEPTACLE	PLUG	RECEPTACLE	PLUG	RECEPTACLE	PLUG
2-POLE 2-WIRE	1 125 V	1-15R	1-15P								
	2 250 V		2-15P	2-20R	2-20P	2-30R	2-30P				
	3 277 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
	4 600 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
2-POLE 3-WIRE GROUNDING	5 125 V	5-15R	5-15P	5-20R	5-20P	5-30R	5-30P	5-50R	5-50P		
	6 250 V	6-15R	6-15P	6-20R	6-20P	6-30R	6-30P	6-50R	6-50P		
	7 277 V AC	7-15R	7-15P	7-20R	7-20P	7-30R	7-30P	7-50R	7-50P		
	24 347 V AC	24-15R	24-15P	24-20R	24-20P	24-30R	24-30P	24-50R	24-50P		
	8 480 V AC	(RESERVED FOR FUTURE CONFIGURATIONS)									
	9 600 V AC	(RESERVED FOR FUTURE CONFIGURATIONS)									
3-POLE 3-WIRE	10 125/250 V			10-20R	10-20P	10-30R	10-30P	10-50R	10-50P		
	11 3 φ 250 V	11-15R	11-15P	11-20R	11-20P	11-30R	11-30P	11-50R	11-50P		
	12 3 φ 480 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
	13 3 φ 600 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
3-POLE 4-WIRE GROUNDING	14 125/250 V	14-15R	14-15P	14-20R	14-20P	14-30R	14-30P	14-50R	14-50P	14-60R	14-60P
	15 3 φ 250 V	15-15R	15-15P	15-20R	15-20P	15-30R	15-30P	15-50R	15-50P	15-60R	15-60P
	16 3 φ 480 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
	17 3 φ 600 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
4-POLE 4-WIRE	18 3 φ 208Y/120 V	18-15R	18-15P	18-20R	18-20P	18-30R	18-30P	18-50R	18-50P	18-60R	18-60P
	19 3 φ 480Y/277 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
	20 3 φ 600Y/347 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
4-POLE 5-WIRE GROUNDING	21 3 φ 208Y/120 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
	22 3 φ 480Y/277 V	(RESERVED FOR FUTURE CONFIGURATIONS)									
	23 3 φ 600Y/347 V	(RESERVED FOR FUTURE CONFIGURATIONS)									

Appendix H-2

NEMA CONFIGURATIONS FOR LOCKING PLUGS & RECEPTACLES			15 AMPERE		20 AMPERE		30 AMPERE	
			RECEPTACLE	PLUG	RECEPTACLE	PLUG	RECEPTACLE	PLUG
2-POLE 2-WIRE	125 V	L1	L1-15R	L1-15P				
	250 V	L2			L2-20R	L2-20P		
	277 V AC	L3	F	U	T	U	R	E
	600 V	L4	F	U	T	U	R	E
2-POLE 3-WIRE GROUNDING	125 V	L5	L5-15R	L5-15P	L5-20R	L5-20P	L5-30R	L5-30P
	250 V	L6	L6-15R	L6-15P	L6-20R	L6-20P	L6-30R	L6-30P
	277 V AC	L7	L7-15R	L7-15P	L7-20R	L7-20P	L7-30R	L7-30P
	480 V AC	L8			L8-20R	L8-20P	L8-30R	L8-30P
	600 V AC	L9			L9-20R	L9-20P	L9-30R	L9-30P
3-POLE 3-WIRE	125/250 V	L10			L10-20R	L10-20P	L10-30R	L10-30P
	3Ø 250 V	L11	L11-15R	L11-15P	L11-20R	L11-20P	L11-30R	L11-30P
	3Ø 480 V	L12			L12-20R	L12-20P	L12-30R	L12-30P
	3Ø 600 V	L13					L13-30R	L13-30P
3-POLE 4-WIRE GROUNDING	125/250 V	L14			L14-20R	L14-20P	L14-30R	L14-30P
	3Ø 250 V	L15			L15-20R	L15-20P	L15-30R	L15-30P
	3Ø 480 V	L16			L16-20R	L16-20P	L16-30R	L16-30P
	3Ø 600 V	L17					L17-30R	L17-30P
4-POLE 4-WIRE	3Ø 208Y/120 V	L18			L18-20R	L18-20P	L18-30R	L18-30P
	3Ø 480Y/277 V	L19			L19-20R	L19-20P	L19-30R	L19-30P
	3Ø 600Y/347 V	L20			L20-20R	L20-20P	L20-30R	L20-30P
4-POLE 5-WIRE GROUNDING	3Ø 208Y/120 V	L21			L21-20R	L21-20P	L21-30R	L21-30P
	3Ø 480Y/277 V	L22			L22-20R	L22-20P	L22-30R	L22-30P
	3Ø 600Y/347 V	L23			L23-20R	L23-20P	L23-30R	L23-30P

Appendix I Long-term Maintenance Guidelines

This Appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.

I-1 Introduction. This appendix deals specifically with the maintenance of equipment that, by nature of its application, necessitates long intervals between shutdowns. It should be stressed that environmental or operating conditions of a specific installation must be considered and may dictate a different frequency of maintenance than suggested in this appendix.

Maintenance guidelines are presented in the tabular form for the following equipment.

I-2 Medium-Voltage Equipment.

1. Cables.
2. Liquid-filled Transformers.
3. Dry-type Switchgear.
4. Metal-clad Switchgear.
5. Circuit Breakers.
6. Metal-Enclosed Switches.
7. Buses and Bus Ducts.
8. Protective Relays.
9. Automatic Transfer Control Equipment.
10. Fuses.
11. Lightning Arresters.

I-3 Medium- and Low-Voltage Equipment.

1. Outside Overhead Electric Lines.

I-4 Low-Voltage Equipment.

1. Low-Voltage Cables and Connections.
2. Dry-type Transformers.
3. Switchgear.
4. Draw-out-type Circuit Breakers.
5. Buses and Bus Ducts.
6. Panelboards.
7. Protective Relays.

Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution, I-2 Medium Voltage Equipment, 1-Cables, Terminations and Connections

Type	Inspections, Maintenance and Tests	Typical Frequency and Remarks
Solid Dielectric (Chapter 8)	**Inspections (while energized) of** (8-2.1):	One year.
	Conduit entrances (8-4).	Observe for deformation due to pressure and for bends with radius less than minimum allowed.
	Poles and supports.	Ditto.
	Binder tape terminations (aerial cables) (8-3).	Ditto.
	Ends of trays (8-4).	Ditto.
	Splices (8-2.3).	Ditto.
	Terminations (stress cones and potheads) (8-2.3) (8-2.5).	Ditto plus dirt, tracking, water streaks, chipped porcelain, shield ground connections (where visible) and adequate clearances from grounded metal parts.
	Fireproofing (where required) (8-2.3).	Observe for continuity.
	Loading.	Make certain loads are within cable ampacity rating.
Varnished Cambric Lead Covered and Paper Insulated Lead Covered	**Inspections (while energized) of** (8-2.1):	
	Same as above.	Same as above.
	Lead sheath (8-2.3).	Observe for cracks or cold wipe joints — often indicated by leakage of cable oil or compound.
All Types	**Major Maintenance and Testing (de-energized)** (5-3) (8-2.1):	Three to six years.
	Complete inspection same as above.	Same as above.
	Clean and inspect porcelain portions of potheads (8-2.5) (6-1.2.1).	For cracks and chips.
	Clean and inspect stress cones and leakage sections (8-2.3) (6-2.13).	For soundness of stress cones. X-ray or disassemble, if soft spots are detected. For surface tracking.
	Check plastic jackets for longitudinal shrinkage from splices and terminations.	Jacket shrinkage might have damaged shielding tapes or stress cones.
	Check integrity of shield grounding (8-2.3).	Observe ground connections for stress cones. Suggest checking electrical continuity of shielding tape.
	Check general condition of cable (8-2.3).	Does insulating material appear to have been damaged by overheating?
	Observe connectors for overheating (8-2.5) (6-1.3) (6-2.14).	Discoloration and/or oxidation indicate possible problem. Check bolts for tightness, if accessible. If connectors are insulated with tape, deterioration or charring of tape is indicative of overheated connector, caused by loose bolts, etc. Infrared survey while conductors are energized and loaded to at least 30 percent of ampacity may be beneficial to detect overheated connections. Use good quality infrared scanning equipment.
	Test cable insulation with high potential DC (8-5) (18-9.1).	Disconnect cables from equipment and provide corona protection on ends. Ground other conductors not being tested. Record leakage current in microamperes at each test voltage level. Record temperature and relative humidity.
	Determine condition of cable insulation (18-9.2.4.3).	Interpret test results, considering length of cable, number of taps, shape of megohm or leakage current curve, temperature and relative humidity.
	Reconnect cables to equipment.	Tighten connectors adequately.
	Aluminum conductors.	Make certain that connectors of the proper type are correctly installed. Use Belleville washers when bolting aluminum cable lugs to equipment. Advisable to determine conductivity of connection using microhmmeter or determine voltage drop under test load conditions. (18-12).

Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution, I-2 Medium Voltage Equipment, 2-Liquid-filled Transformers

Type	Inspections, Maintenance and Tests	Typical Frequency and Remarks
(Oil and Askarel) Sealed Tank, Conservator and Gas Sealed Systems (Chapter 7)	**Inspections (while energized) of:**	Weekly to monthly.
	Top liquid temperature (7-2.4).	Record findings. Present temperature and highest indicated. Reset drag needle. 80°C nominal max. permitted.
	Head space pressure (sealed tank type) (7-2.5.2).	Should vary under changes in loading and ambient temperature. If gauge remains at zero, gauge is broken or leak exists in tank head space which permits transformer to breathe and allows entrance of moisture.
	Nitrogen pressure (pressurized tank type).	Check nitrogen bottle pressure and pressure in transformer head space.
	Liquid level in tanks (7-2.5.1).	Should be between min. and max. marks on gauge.
	Liquid levels in oil-filled bushings (if so equipped).	Should be between min. and max. marks on gauge.
	Evidence of oil leaks (7-2.7.4).	From tanks, fittings, cooling tubes and bushings.
	Automatic load tap changer mechanism.	General condition; note and record number of operations.
	Tests (while energized) of:	
	Oil — draw sample and test in laboratory for (7-2.8) (7-2.8.6).	Annually for normal service transformers. Biannually for rectifier and arc furnace transformers. Dielectric strength, acidity, and color. If dielectric is low, determine water content.
	Askarel — draw sample and test in laboratory for (7-2.8) (7-2.8.6). (Observe EPA regulations for handling and disposal.)	Same frequency as for oil. Dielectric strength, acidity, color, and general condition. If dielectric is low determine water content.
	Comprehensive liquid tests (7-2.8.6).	Frequency three to six years. In addition to above, tests include interfacial tension, water content, refractive index power factor at 25° and 100°C (18-9.3.2) corrosive sulphur (Askarel), and inclusion of cellulose material.
	Dissolved gas content in liquid of transformers in critical service or in questionable condition as might be indicated by above liquid tests (18-16).	Frequency six years or as conditions indicate. Draw sample in special container furnished by test laboratory. Spectrophotometer test will detect gases in oil caused by certain abnormal conditions in transformer. A series of tests on samples drawn over period of time may be necessary to determine if abnormal condition exists and to determine problem. Devices are available for installation on transformers to collect gases to be tested for combustibility to determine if internal transformer problem exists.
	Major Maintenance and Tests (de-energized) (5-3) (7-2.7.2):	Three to six years or more often if above tests indicate.
	Make above tests well in advance of scheduled shutdown.	Determine possible problems that require attention.
	Inspect pressure relief diaphragm for cracks or holes or mechanical pressure relief device for proper operation (7-2.7.3).	Replace if defective. Possible cause of pressure in sealed type transformers remaining at zero.
	Pressure test with dry nitrogen the head space areas of sealed type transformers if pressure gauge remains at zero and pressure relief device is satisfactory.	Apply liquid along seams, etc., to locate leaks. Make necessary repairs.
	Clean bushings and inspect surfaces (7-2.7.3).	Consider application of silicone grease in badly contaminated areas. Should be removed and reapplied at maximum two-year intervals, preferably one year.

Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution, I-2 Medium Voltage Equipment, 2-Liquid-filled Transformers (Continued)

Type	Inspections, Maintenance and Tests	Typical Frequency and Remarks
(Oil and Askarel) Sealed Tank, Conservator and Gas Sealed Systems (Cont.)	**Major Maintenance and Tests (de-energized) (Cont.):**	
	Inspect load tap changer mechanism and contact.	Follow manufacturer's instructions on maintenance and number of operations between contact replacements.
	Paint tank as required.	Wire-brush rust spots and prime paint. Finish paint.
	Check ground system connections (7-2.7.5).	
	Perform turns ratio tests (18-11).	In each tap position. As an acceptance test and after major repairs.
	Perform power factor tests (disconnect from equipment) (18-9.3.2).	Windings, bushings and insulating liquid.
	Consider making winding/tap changer resistance tests.	Use microhmmeter. In each tap position to detect abnormally high contact resistance.
	Make undercover inspection through manholes (provide positive protection to prevent entrance of moisture) (7-2.7.6). This inspection may not be necessary at six-year intervals unless tests indicate problems.	Six-year frequency should definitely be considered for rectifier and arc furnace transformers. Inspect for moisture or rust under cover, water on horizontal surfaces under oil, tap changer contacts (insofar as possible), trash, oil sludge deposits, loose bracing and loose connections.
	Consider high-potential DC tests (7-2.9.4) (18-5 through 18-8).	DC in excess of 34 kV may polarize liquid and thereby increase leakage currents.
	If above inspections and/or tests indicate possible internal problems, it may be necessary to transport transformer to shop to untank the core and coil assembly for cleaning, inspecting, testing and making repairs as found necessary.	
	Filtering insulating liquid (de-energize transformer and ground windings) (7-2.8.6.3).	Frequency as required. Remove moisture by heating and pumping liquid through cellulose filters, a centrifuge or a vacuum dehydrator. Thoroughly clean hoses and filtering equipment before switching from oil to Askarel or vice versa (7-2.1.2). Observe ANSI C107.1, 1974 for handling and disposal of Askarel.
	Re-refining insulating oil (de-energize transformer and ground windings) (7-2.8.6.3).	Frequency as required. Filter through fuller's earth to remove polar compounds and acids. Add dibutylparacresol to replace oxidation inhibitors.
	Refilling transformer with insulating liquid (7-2.7.7 & 7-2.7.8).	Refill under partial vacuum if transformer tank is so designed. Follow manufacturer's instructions. Always test insulating liquid for dielectric strength (min. 26 kV for oil) prior to pumping into transformer and pump through filter (min. 30 kV Askarel).
	Special Testing (de-energized):	
	Induced potential test (7-2.9.5).	To test phase-to-phase and turn-to-turn insulation. (200 to 300 Hz for 7200 volt cycles). Proof test.
	AC high potential test (18-9.3.1).	Proof test.

Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution, I-2 Medium Voltage Equipment, 3 Dry-type Transformers

Type	Inspections, Maintenance and Tests	Typical Frequency and Remarks
Ventilated (Indoors). (7-1 & 7-3)	**Inspections (while energized) of:**	Weekly to monthly. Record findings.
	Operating temperature (7-3.4).	Present temperature and highest indicated. Reset drag needle. 150°C is max. operating temperature for transformers rated 80°C rise. 220°C is max. operating temperature for transformers rated 150°C rise.
	Cleanliness of screens located over or behind ventilation louvers in enclosure (7-3.6).	Clogged screens restrict ventilation and thereby increase operating temperature of core and coil assembly. Vacuum screens without de-energizing transformer if dust and lint are on outside of screens. If same is on inside, transformer must be de-energized and enclosure sides removed to clean screens.
	Ventilating fan operation (if so equipped.)	Check operation of fans with control switch in "Manual" position. Do not operate fans continuously with switch in "Manual"; leave in "Automatic" so temperature detectors will operate fans at temperatures above specified levels. Also check alarm contacts for proper operation at excessive temperature levels.
	Room ventilation (7-3.6).	Adequate ventilation system to admit and exhaust air. Air streams should not be directed toward upper vent louvers in transformer enclosure because it will restrict ventilation inside transformer and cause overheating.
	Evidence of condensation and water leaks in room (7-3.6).	Inspect top of transformer. Make necessary corrections.
	Major Maintenance (de-energized) (7-3.7) (5-3):	Three to six years. More often if required.
	Remove enclosure covers and clean vent louvers and screens (7-3.7.2).	
	Clean insulators, core and windings (7-3.7.2 & 7-3.7.3).	Use bottle of dry nitrogen with pressure regulator, hose and small nozzle to blow off dust. Restrict pressure to 30 psi max. Clean with soft bristle brush as required.
	Inspect following components:	
	Interphase barriers (7-3.7.2).	Should not touch windings.
	Wedges and clamping rings (7-3.7.2).	For proper clamping of windings. Tighten as required.
	Primary and secondary buses and conductors (7-3.7.2) (6-1.3).	For tightness of connections.
	Porcelain insulators (6-1.2).	For chips, cracks and water steaks.
	Insulating materials (7-3.7.2) (6-2.10 through 6-2.14).	For surface tracking.
	Windings (7-3.7.2) (6-2.14) (7-3.7.3).	For damage to insulation, including overheating.
	Tap connections (7-3.7.2).	For tightness and correctness to provide proper voltage.
	Core assembly.	For loose and/or dislocated laminations, localized or general overheating and for integrity of ground strap which is *only* place where core assembly is permitted to be grounded.
	Ventilating channels between core and windings and between windings (7-3.7.3).	For clogging with lint, dust or tape used to hold spacers, etc., in place during assembly. Clean as required to allow proper air flow.
	Space heaters for proper operation.	Used to keep windings dry when transformer is de-energized.
	Temperature detectors.	For proper location and proper support of leads.
	Temperature indicators.	For accuracy and operation of fan and alarm contacts at proper temperatures.
	Cooling fans.	For free turning and proper operation.

Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution, I-2 Medium Voltage Equipment, 3 Dry-type Transformers (Continued)

Type	Inspections, Maintenance and Tests	Typical Frequency and Remarks
Ventilated (Indoors) (Cont.)	**Testing (de-energized)** (18-1) (18-4 through 18-8):	Three to six years. More often if required.
	Turns ratio test (18-11).	In each tap position as an acceptance test and after major repairs.
	Polarization index test (7-2.9.1) (7-2.9.2 & 7-2.9.3) (18-9).	Use 1000 volt insulation resistance tester. Low P.I. results often indicates moisture in winding. If so, investigate cause and satisfactorily dry transformer before making high potential DC test and returning transformer to service.
	High potential DC test (7-2.9.4) (18-9.2.4).	Record leakage currents in microamperes, temperature and relative humidity.
	Special Testing (de-energized):	
	Induced potential test (7-2.9.5).	To test phase-to-phase and turn-to-turn insulation. (200 to 300 Hz. for 7200 volt cycles.) Proof test.
	AC high potential test (18-9.3.1).	Proof test.

Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution, I-2 Medium Voltage Equipment, 4-Metal-clad Switchgear

Type	Inspections, Maintenance and Tests	Typical Frequency and Remarks
Indoor (Chapter 6)	**Inspections (while energized):**	Three to six months.
	Open external doors and inspect components:	
	Fronts of circuit breakers.	Record number of operations.
	Protective and control relays (6-8.7).	Wiring and connections — not internals.
	Auxiliary devices, wiring and terminal blocks (6-4.6).	Proper indicating lights should light.
	Space heaters (6-2.7).	Operate continuously to overcome possible malfunction of thermostats. Consider installation of ammeters in heater supply circuits to monitor full load current of heaters on each circuit to assure that all are operating.
	Ventilation (6-2.8).	Ventilation louvers should be open.
	Insulators and insulating materials (6-2.10 through 6-2.14).	
	Cable terminations (8-1 through 8-4).	Observe stress cones and leakage sections annually for cleanliness and tracking.
	Batteries (6-8.4).	
	Also inspect for following conditions:	
	Loading.	Record loads.
	Cleanliness (6-2.9).	Moderate amount of dry nonconductive dust not harmful.
	Dryness (6-2.5 & 6-2.6).	Evidence of condensation or water leaks.
	Rodents and reptiles (6-2.4).	
	Overheating of parts (6-2.14).	Discoloration and/or oxidation indicate possible problem.
	Tracking on insulating surfaces (6-2.13).	Take necessary corrective action.

Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution, I-2 Medium Voltage Equipment, 4-Metal-clad Switchgear (Continued)

Type	Inspections, Maintenance and Tests	Typical Frequency and Remarks
Indoor (Cont.)	**Major Maintenance or Overhaul:**	Three to six years, depending on ambient conditions.
	De-energize (5-3). **Verify that no parts of the power or control circuitry are energized by "back feed" from alternate power or control sources.** Completely clean, inspect, tighten and adjust all components (6-4.1):	Follow manufacturer's maintenance instructions.
	Structure and enclosure (6-2.3 & 6-2.4).	Wire-brush and prime paint rust spots. Finish paint.
	Ventilating louvers and air filters (6-2.8).	Clean or replace filters as required.
	Buses, splices and bolts (6-1.3) (6-2.14).	Check bolts for manufacturer's recommended torque. If inaccessible, check insulating tape, boot or compound box over bus splices for heat deterioration due to loose bolts, etc.
	Insulators and insulating materials (6-2.10 through 6-2.14) (6-1.2).	Clean and inspect for surface tracking.
	Circuit breakers (6-4 through 6-6).	Refer to Oil and Air Circuit Breaker sections.
	Breaker disconnect studs and finger clusters (6-4.3.7).	Lubricate, unless manufacturer's instructions specify that they should not be lubricated.
	Draw-out breaker racking mechanisms (6-1.7).	Alignment and ease of operation.
	Cable terminations and connections (8-1 through 8-4).	Clean and inspect for surface tracking. Check connections for tightness.
	Meters (6-8.7).	Test for accuracy.
	Controls, interlocks and closing power rectifiers (6-8.8).	Make functional tests. Check voltages.
	CT's, PT's and control power transformers (6-8.5).	
	Fuse clips and fuses (13-2).	Check clips for adequate spring pressure.
	Grounding (6-1.5) (6-8.9).	Proper fuse rating.
	Components and conditions in above block.	Make necessary repairs.
	Testing (Chapter 18) (5-3):	Three to six years, depending on ambient conditions.
	Test buses, breakers, PT's, CT's and cables with high potential DC.	Record leakage currents in microamperes (18-9.2.4) (8-5).
	Calibrate and test protective relays (18-10.3).	Refer to Protective Relays section.
	Functionally trip breakers with relays (18-10.3.2.7).	Preferably, inject test current into CT and relay circuits.
	Test conductivity of aluminum cable connections (18-12) (6-1.3).	Use microhmmeter or determine voltage drop under test load conditions.
	Test wiring for controls, meters and protective relays for insulation resistance (18-9.2.1).	1000 volt DC for control wiring. 500 volt DC for meters and relays.
Outdoor	**Inspections (while energized):** Same as for indoor gear except:	One to three months.
	Special emphasis on evidence of condensation and water leaks (6-2.3) (6-2.5) (6-2.6).	Rust spots on underside of metal roof indicative of condensate.
	Special emphasis on space heater operation (6-2.7).	
	Ventilating louvers and air filters and cleanliness (6-2.8).	Clean or replace air filters as required.
	Major Maintenance or Overhaul: De-energize (5-3). **Verify that no parts of the power or control circuitry are energized by "back feed" from alternate power or control sources.** Same as for indoor gear.	Three years. More often if conditions require. Follow manufacturer's maintenance instructions.
	Testing (Chapter 18) (5-3): Same as for indoor gear.	Three years. More often if conditions require.

Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution, I-2 Medium Voltage Equipment, 5-Circuit Breakers

Type	Inspections, Maintenance and Tests	Typical Frequency and Remarks
Air-break, Draw-out Type (6-4)	**Inspection and Maintenance (withdrawn from switchgear and de-energized)** (5-3):	Max. of three years or at manufacturer's maximum number of operations since previous maintenance, whichever occurs first. Immediately after breaker opens to interrupt a serious fault. Follow manufacturer's maintenance instructions. If breaker is stored energy closing type, follow manufacturer's safety precautions, determine that closing springs are discharged, or mechanism is blocked to prevent personal injury. Keep hands away from contacts and mechanism while test operating breaker (6-4.1.1).
	Remove arc chutes. Inspect, adjust and clean where necessary:	
	Main contacts (6-4.3).	For pitting, spring pressure, overheating, alignment, overtravel or wipe. Adjust or replace accordingly.
	Arcing contacts (6-4.3.2).	For alignment, overtravel or wipe and for arc erosion. Adjust or replace accordingly.
	Moving parts and linkages (6-4.5.1 through 6-4.5.3).	For freedom of movement.
	Closing mechanism (6-4.5).	For quick and positive closing action.
	Tripping mechanism (6-4.5).	For freedom of movement and reliability to open breaker contacts.
	Interlocks and safety devices (6-8.8) (6-4.6.2).	Functionally test to prove proper operation.
	Primary disconnect finger clusters (6-4.3.7).	For proper adjustment and spring pressure. Lubricate, unless manufacturer's instructions specify that they should not be lubricated.
	Secondary disconnect contacts (6-4.3.7).	For alignment and spring pressure. Lubricate.
	Closing and trip coils (6-4.6.1.)	General condition and evidence of overheating.
	Spring charging motor and mechanism (stored energy type) (6-4.6.1).	Proper operation. Oil leaks from gear motor.
	Shunt trip device (6-4.6.1).	For freedom of movement. Functionally test.
	Undervoltage trip device.	For freedom of movement. Functionally test.
	Auxiliary contacts.	For proper operation with closing and opening of breaker.
	Closing (x and y) relays (electrically operated breakers).	Contact erosion. Dress or replace as required.
	Current transformers (6-8.7.2) (6-2.10).	General condition. Check nameplate ratio.
	Connection bolts (9-3.1 through 9-3.3).	Check for tightness.
	Structure or frame.	For proper alignment and loose or broken parts.
	Fuses and mountings (13-1 & 13-2).	General condition and tightness.
	Frame grounding device.	Connect before and disconnect after primary fingers.
	Position indicators (6-4.6.2) (6-8.6.2).	For proper operation.
	Auxiliary wiring.	General condition and tightness of terminal screws.
	Arc chutes (6-4.4).	For broken parts, missing arc splitters, and amount of metal spatter and burning on interior surfaces. Snuffer screens must be clean. Repair or replace as necessary.
	Operation counter.	For proper operation. Record number of operations.
	Insulators and insulating materials (6-2.10, 6-2.12 & 6-2.13) (6-4.2).	For cracks, breaks, corona, tracking and overheating.
	Breaker auxiliary devices (6-4.6).	Make necessary repairs.